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FORMATION OF COAL BEDS

BY

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PROCEEDINGS OF THE AMERICAN PHILOSOPHICAL SOCIETY

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PREFACE.

The writer's monograph, "Carboniferous of the Appalachian Basin," was an effort to correlate the coal and other horizons, that a basis might be obtained for intelligent discussion of formation of coal beds. Detailed studies by government geologists have proved that several tentative correlations, made where the available information was imperfect, are erroneous, but the scheme, presented in that monograph, has been confirmed in all essential features and it serves as a safe basis for the discussion.

When, by retirement, the writer regained the "leisure" belonging to college professors, a generation ago, this work was undertaken systematically. But it was discovered quickly that the Appalachian Basin, though of vast extent, could serve only as a beginning: the problem is world-wide, so that study of literature in many lands became necessary. Another discovery followed quickly—that the writer's stock of ignorance and misinformation was very great. It is said that misery loves company; be that as it may, confession must be made that the writer's pain was mitigated by the further discovery that his fellow geologists are equally provincial. Whether or not the writer has overcome his provincialism and the influence of deep-seated erroneous opinions, must be determined by the reader.

There may be disappointment because some eminent students have found no place in these pages and because some important phenomena have received only passing reference. But it was not the writer's intention to prepare a Thesaurus of information respecting coal; the effort was to find solution for a definite problem. There are serious limitations of space and time—especially of time, where one has passed the allotted period of three score years and ten. In preparing the text, it was essential to select closely from the material, so that several hundred synopses were laid aside and merely incidental reference was made to others, leading to omission

of all mention of nearly two hundred authors, whose work bears more or less directly upon the matters at issue. It is quite certain that many of them will find place in another work now in progress. The citations, except where otherwise stated, are all at first hand, and in every case, the whole memoir or volume has been read, so as to avoid danger of misinterpretation by quoting sentences apart from the context.

It is almost invidious to express obligations to any apart from all, for the experience has proved anew that geologists are a whole-souled race. Assistance has been rendered freely and without reserve, not only by those who have shown friendship and confidence during many years, but also by those, in this and other lands, to whom the writer is only a name. But it is impossible to avoid expressing earnest thanks to I. C. White, D. White and C. Barrois, who, by timely suggestions, removed serious perplexities and thereby added to an already great debt, which cannot be paid and can receive only gratitude as interest. At the same time, it must be remembered that these students are in no wise responsible for the writer's conclusions, which in some cases are notably at variance with theirs.

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THE FORMATION OF COAL BEDS.

I.

AN HISTORICAL SUMMARY OF OPINION FROM 1700 TO THE PRESENT TIME.

By JOHN J. STEVENSON.

(Read April 21, 1911.)

PRELIMINARY NOTE.

Preparation of a monograph on any subject which interests students in many lands requires thorough study of the literature as a preparatory step. But that literature has grown to such proportions that one often becomes discouraged and is burdened with the fear that life will be spent in making ready and that the grave will have been reached before the monograph has been begun. Yet such preliminary research is not without compensation, for one discovers that his own period is not so far in advance of days gone by as he had supposed; that his contemporaries, with all their advantages, have done little more, in many instances, than to place newer and finer clothing on the generalizations of earlier students who had worked within narrower areas.

This is not to say that modern workers have appropriated knowingly the results obtained by their predecessors. The writer has discovered very few instances of that sort. For the most part, generalizations have been made, *de novo*, in ignorance of those previously formulated. The literature has become vast; the papers are scat-

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tered in publications of many societies in six or more languages; many were merely separate pamphlets, now almost inaccessible. Great scientific libraries are few and they are beyond reach of the ordinary field-worker; while college professors and men connected with official surveys rarely have leisure needed for thorough research. The necessity for prompt publication, that fellow workers may have the advantage of one's results, makes long preliminary study almost impossible, in some cases almost unjustifiable.

The writer, looking forward to preparation of a monograph on formation of coal beds, has examined many hundreds of publications varying from mere notices to ponderous quartos and this preliminary work is still far from complete. During the examination, he has discovered not only that there is little new under the sun but also that much, which is good and important, soon passes from men's minds. He has discovered also that owing to quotation at second-hand, without verification, some conclusions offered by the earlier students have been misunderstood or even misinterpreted, so as to discredit the authors. He has become convinced that a systematic presentation of conclusions reached by his predecessors would not be useless or unacceptable; it would exhibit the gradual development of opinion and it would lead to proper appreciation of investigations made and conditions, which, in this day, would be regarded as unfavorable; it would aid the students hereafter by indicating the road along which to pursue his preliminary examination. Such presentation is offered in the succeeding pages.

In preparing this historical summary, the writer, recognizing the necessary limits of space, is compelled to note only such publications as deal especially with the topic under consideration; and of those, only such as are the outcome of direct study. The reader may be disappointed by the omission of some authors and by the admission of others; but this is unavoidable. Many important reflections have been made by writers incidentally; those will be noted in the final discussion. No reference to opinions respecting the origin of coal is given, except in cases where that question is basis of the author's conclusion respecting the mode of accumulation.

The plan of the summary may be open to criticism. The

original plan was to arrange the synopses topically, but this separated the contrasting opinions of contemporaries; the chronological arrangement is open to the objection, that it breaks up the line of argument for or against an hypothesis. Yet the latter seems preferable as more in accord with the purpose of the summary. It has been followed, except where it would fail to show an author's final conclusions or where it seemed necessary to bring together widely separated observations upon a special phase.

THE HYPOTHESES.

There has been little diversity of opinion respecting the origin of coal. Geologists and chemists, with rare exceptions, have recognized that the several types consist mainly of vegetable matter which has undergone chemical change. But no such consensus of opinion exists respecting the mode of accumulation in beds; geologists, for about one hundred and thirty years, have been divided into two opposing camps with here and there an individual warrior carrying on an independent strife.

The older hypothesis was suggested more than two centuries ago, prior to the era of investigation, and it remained unchallenged until the latter part of the eighteenth century, but it fell into disfavor early in the nineteenth century. Thereafter, it had few, but earnest defenders until within the last thirty years, during which it has been urged with great energy. This, the doctrine of allochthonous origin, conceives that coal beds are composed of transported vegetable matter deposited in the sea or in lake basins. The conception has assumed many forms but the essential feature of transport is common to all.

The other hypothesis, formulated in 1778 as the result of broad field observations gained general acceptance about one hundred years ago; since that time, it has been held in one form or another by a majority of geologists who have studied the coal measures. It is known as the doctrine of growth *in situ*, but von Gümbel's term, autochthonous, has come into general use. According to this hypothesis, the plants which yielded the vegetable matter grew where the coal is found, analogous conditions being found in great peat accumulations, especially those of the cypress swamps of North

America. That additional material may be brought in from time to time by transport is conceded, but the quantity thus added is comparatively unimportant. Equally the formation of a coal deposit by transport is conceded but not the formation of a typical coal bed.

THE SYNOPSIS OF OPINIONS AND RESULTS.

Woodward¹ explained all stratified rocks as deposits from the original menstruum. During the time of the deluge, the solid materials were wholly "dissolved." They were mingled with unconsolidated materials such as sand, earth as well as animal and vegetable matters and all were assumed and sustained by the water in a confused mass. In time, these materials subsided "as near as possibly could be expected in so great confusion, according to the laws of gravity," those having the least gravity settling last of all and covering the rest. "The matter, subsiding thus, formed the strata of stone, of marble, of cole, of earth and the rest." That Woodward thought coal to be of vegetable origin cannot be determined with certainty; his remark that vegetable materials, being of less specific gravity than mineral matter, would be precipitated last of all and so form the outermost "stratum of the globe" seems to suggest a contrary belief.

Whiston² took issue with Woodward and asserted that the hypothesis presented by that author "includes things so strange, wonderful and surprizing that nothing but the utmost Necessity, and the perfect unaccountableness of the Phenomena without it, ought to be esteemed sufficient to justify the Belief and Introduction of it." At the time of the Noachic deluge the earth passed through the "Chaotick Atmosphere of a Comet" and thus acquired a great amount of new material which mingled with the loose materials of the globe. These subsided according to the laws of specific gravity, giving the strata of stone, earth and coal; in all about 105 feet thick. Whether the coal is terrestrial or cometary in origin cannot be ascertained by study of this work. The author's conclusions are

¹ J. Woodward, "An Essay Toward a Natural History of the Earth and Terrestrial Bodies," 2d ed., London, 1702, pp. 73, 74, 77.

² W. Whiston, "A New Theory of the Earth," 4th ed., London, 1725, pp. 277, 278, 365, 419, 423, 425.

fortified by a wealth of mathematical proof which, apparently, leaves little to be desired.

Scheuchzer³ described a deposit of black slate in the canton of Glarus, occurring in layers, one third of an inch thick, each consisting of a hard upper and a soft lower lamina. The phenomena observed in the quarry led him to assert "This is now certain that all rock beds were formed by precipitation, through subsidence of heavier earthy particles in a fluid menstruum, especially the waters of the Deluge. The observed difference of materials in every layer as well as the orderly parallelism of the layers is a sufficient proof of this. . . . At times all sorts of relics of the Deluge, fish and vegetables occur in these shales." Scheuchzer saw in the coal merely the remains of wood swept off during the deluge, "Wherefore here and there stone coals are found which were true wood"; and he notes the existence of deposits at 18 to 24 yards below the surface. This is his "*Lignum fossile ex Sylva submersa.*"

De Jussieu,⁴ about 1740, observed, near St. Chaumont in France, many impressions of plants very different from those now existing. He remarked that these represent true plants and that they lie flat as in a herbarium. In seeking their origin he was led to believe that they were vegetation of a warm climate and that they had been transported. The sea covered the continents; the currents carried and deposited the plants and shells which are found petrified.

Few writers prior to the middle of the eighteenth century dealt in other than *a priori* arguments but, after half the century had passed, there came numerous observers whose labors were utilized by Buffon.

Buffon⁵ recognized the vegetable origin of coal and asserted that its excellent quality is due to the intimate mingling of vegetable matter with bitumen—the latter being only vegetable oil or animal fat impregnated with acid. He designates coal as "*Charbon de*

³J. J. Scheuchzer, "*Meteorologia et oryctologia helvetica*," Zurich, 1718, pp. 110, 111, 239, 240.

⁴A. de Jussieu, cited from Saporta by L. Lesquereux, 2d Geol. Survey of Penn., Ann. Rep. for 1885, p. 95.

⁵L. de Buffon, "*Histoire naturelle, generale et particuliere*," Sonnini Ed., T. 9me., Paris, An IX., pp. 11, 14, 16, 35, 36, 42-46. The original publication was in 1778.

terre" and restricts the term "houille" to "the black combustible earthly deposits which are often found over and sometimes under the coal beds." These are simply mold mixed with a small amount of bitumen. The slime deposited in the sea, following the slope of the bottom and extending at times for several leagues along the coast is nothing other than the mold of plants and trees, which is drawn off by running water. The vegetable oil of that slime, seized by acids in the sea, will become in time bituminous coal but always light and friable; while the plants themselves, drawn off in like manner and deposited by the waters form the true beds of charbon de terre, of which the characteristics are very different from those of houille, the charbon being heavier, more compact and swelling in the fire.

The dips of the coal are due to the general law of deposit in moving water, while at the same time the materials have taken the inclination of the surface on which they were laid down. Occasionally the dip approaches the vertical, but even that great inclination gradually approaches the horizontal more and more as one descends and at last the horizontal plane, the plateau, is reached. A usual feature is that the thickness of a coal bed increases with the depth and the maximum is *en plateau*—which is in accordance with the law of deposit of materials carried by water and laid down on a sloping surface. The same law applies to other materials, whereby is explained easily the parallelism of coal beds to each other and to the intervening strata.

Von Beroldingen⁶ published his work in the same year; it was based on broad field study. In it the author maintained that stone coals had originated from brown coals and those in turn from peat. This appears to be the first definite assertion of the peat-bog or *in situ* hypothesis.

De Luc⁷ published the same theory during the next year in the

⁶v. Beroldingen, "Beobachtungen, Zweifel und Fragen, die Mineralogie betreffend," Erster Versuch, Hannover, 1778. The writer has been unable to find a copy of this work. It is cited by De Luc (1779), Mietzsch (1875) and by several other authors.

⁷J. A. De Luc, "Lettres physiques et morales sur l'histoire de la terre et de l'homme," Paris, 1779, Tome V., pp. 213-25. This 126th letter is dated Oldenburg, September 16, 1778.

last of five letters describing the peat deposits of northern Europe. During his journey across Germany and the Baltic he had made many exact observations on bogs; he had followed the great level marshes of the shores up the Weser river to the inland moors and had found the same general features throughout. He describes the slipping of the swamp into the river where, by swelling, it formed a hard dry rampart which prevented all further ingress of water to the swamp. He notes the great flood of Jutland, due to subsidence of the boggy area, which is covered at low tide. On the island of Bornholm in the Baltic is a swamp, surrounded by dunes, which shows many prostrate firs, pointing toward the center of the bog. These trees were overthrown by wind when the peat was soft. He observed that dry peat produces very fine trees, those growing on the peat ramparts of Oldenburg being beautiful. His observations led him to assert that

"The peat is the origin of the pit-coals or charbons de terre." He states in a footnote that he had been anticipated by v. Beroldingen, but that he had arrived at this conclusion independently while studying the immense peat bogs of Bremen. He recalls that islands had sunk below the ocean surface; some of them might contain peat as Bornholm. The waters would deposit matter on the peat giving the shaly roof mingled with leaves of vegetables which covered the peat at time of submergence. New sea deposits accumulated and the peat, compressed, enclosed as in a laboratory, underwent further change. He acknowledges that there may be difficulties in explaining the transmutation of peat and the arrangement of some coal beds, but he is confident that he is on the true road to the proper explanation of the origin of coal and of its occurrence in beds.

An anonymous writer,^a in 1781, sums up the peatbog theory as presented at that time.

It is a received opinion amongst many naturalists, that coal was originally peat moss, this fossil having been found in every intermediate state, nay, sometimes with wood in it, and often with the marks of leaves, roots, branches, and fruits of different plants, shrubs and trees, on the sides of broken fragments. To this doctrine we were made proselytes, being pre-

^a"A Tour to the Caves in the Environs of Ingleborough and Settle in the West-Riding of Yorkshire," London, 1781, p. 68.

sented with some pieces of coal that were got near the top of Wherside and the other mountains, that seemed more like dry clods of peat moss than coal, though distinguishable enough to belong to the latter class. The principal difference in their composition is that coals abound with the vitriolic, and peat moss with the vegetable acid. The vitriolic acid is diffused through every subterranean stratum; hence if a quantity of earth should be superinduced above a stratum of peatmoss, the vitriolic acid that would ouse through, must in time change its nature and turn it into coal: the deeper it lay below the surface of the ground, the more it would be impregnated with this fossil acid, and consequently be the more inflammable. If a stratum should lie near the top of a mountain, there is the less chance that it should be well fed.

Williams* was an uneducated man but an admirable observer, who summarized in his volumes the results of studies in much of Great Britain. He was a firm believer in the vegetable origin of coal and equally in the wide extent of the Noachic deluge. Thinking that he could identify in some coals the wood of modern species, he suggested that, prior to the deluge, only a small part of the globe was inhabited and that most of it was covered with tall trees. Those trees, swept off by the deluge, were carried by currents and deposited in limited areas. But this hypothesis does not satisfy all the conditions, for he had found coals which closely resembled peat. He says, "I will here beg leave to propose another probable source of coal. I believe I may call it a real one, and that is the antediluvian peat bog," and this is followed by a discussion of peat bogs, their structure and growth.

Williams argues strenuously against any hypothesis that the materials of the strata were formed by settling of particles from a heterogeneous mass in accordance with gravity, for the order of the beds is evidence to the contrary. At the same time, he finds in the structure of coal beds evidence that most of the beds were formed of transported timber. "I am of opinion that the antediluvian timber floated upon the chaos or waters of the deluge, . . . and that during the height of the deluge and the time in which the greatest part of the strata were forming, the timber was preparing and fitted for being deposited in strata of coal."

* J. Williams, "The Natural History of the Mineral Kingdom," Edinburgh, 2d ed., 1810, Vol. 1, pp. 510, 522-525. The first edition was in 1789.

Darwin¹⁰ adhered to the doctrine of formation *in situ* but with modifications. "In other circumstances, probably where less moisture has prevailed, morasses seem to have undergone a fermentation, as other vegetable matter; new hay is liable to do so from the great quantity of sugar it contains. From the great heat thus produced in the lower part of the morass, the phlogistic part, or oil or asphaltum, becomes distilled and, rising into higher strata, condensed, forming coal beds of greater or less purity, according to their greater or less quantity of inflammable matter; at the same time the clay beds become poorer or less so as the phlogistic part is more or less completely exhaled from them."

Patrin,¹¹ cited by Parkinson, thought coal and the interposed beds of rock due to alternating ejection of bituminous and earthy materials by submarine volcanoes. In another work cited by Pinkerton he describes the characteristics of coal beds, that they have a boat-like form and that they are never single, there being many in each coal field. He thinks the deposit must have been made in still water. The occurrence of plant impressions in the roof shales has led several naturalists to think that coal is composed of vegetable remains. But Patrin thinks that this opinion presents great difficulties. The naturalist le Blond found beds of coal near Bogota at 13,200 feet above the sea. When the ocean reached that height there would be islands; and it cannot be seen how the small quantity of vegetables, which had been brought accidentally from those mountains, could have formed the thinnest bed of coal or even of peat.

Hutton's¹² opinions appeared in final form in 1795. They are not always stated clearly but the confusion may not be that of the author's mind; it may be only apparent and due to the somewhat involved method of presenting the case. The carbon of coal is evidently of organic origin. Bituminous coal and anthracite are parts

¹⁰ E. Darwin, "Botanical Garden," Add. Notes, XVII., 1791. Cited by J. Parkinson; not seen by the writer.

¹¹ Patrin, Art. Houille, "Dict. d'hist. Naturelle," cited by Parkinson; "Mineralogie, V., p. 317. Cited by J. Pinkerton in "Petrology," pp. 567, 568.

¹² J. Hutton, "Theory of the Earth With Proofs and Illustrations," Edinburg, 1795, Vol. I., pp. 565, 566, 570, 575-581, 586.

of a series, the latter having been derived from the former by the influence of heat, which itself was the agent by which vegetable matter was converted into coal. Fuliginous matter is given off when vegetable materials are burned and it is just what is needed to compose coal beds. There are many charred coal beds, which have lost their volatile or fuliginous matter through subterranean heat. The volatile matter, diffused through the water, aided in formation of the strata, while smoke from burning bodies on the land found its way to the sea where it settled to the bottom. But this was not the only source. The rivers of Scotland carry brown water from the bogs; there must be some agency causing precipitation of this brown material, otherwise the sea would be impregnated with oily substance. The constant perishing of plants and animals would give a supply of oily or bituminous matter to the ocean, which would become pure coal unless earthy stuffs be in the water, which would render the coal impure. If the mixture be perfect and the subsidence uniform, a homogeneous substance resembling cannel would be formed.

Therefore, with regard to the composition of mineral coal, the theory is this, that inflammable vegetable and mineral remains, in a subtilized state, had subsided in the sea, being mixed more or less with argillaceous, calcareous and earthy substances in an impalpable state. Now the chymical analysis of fossil coal justifies this theory; for in the distillation of the inflammable or oily coal, we procure volatile alkali, as might naturally be expected.

Kirwan,¹⁸ indignant at Hutton's generally iconoclastic views, entered the lists evidently determined to annihilate the new doctrines as well as their author. He rejects the hypothesis that pit coal is merely earth or stone impregnated with petrol or asphalt, for Kilkenny coal contains neither petrol nor any other bitumen. He recognizes the vegetable origin of wood coal but maintains that it is chemically different from mineral coal, so different as to show that the latter was not derived from wood deposited in or out of the sea. As further arguments, he notes features in the mode of occurrence. Beds of mineral coal are uniform in thickness within great areas, beds of wood coal are not; beds of mineral coal show parallelism, which is unknown in wood coal beds; wood coal mines

¹⁸ R. Kirwan, "Geological Essays," London, 1799, pp. 315-349.

have sudden elevations or depressions, not found in those of mineral coal; slips or dikes abound in true coal but do not occur in wood coal; wood coal is frequently, genuine coal never found in plains. Mineral coal is of distinctly inorganic origin.

My opinion, therefore, is that coal mines or strata of coal, as well as the mountains or hills in which they are found, owe their origin to the disintegration and decomposition of primeval mountains, either now totally destroyed, or whose height and bulk, in consequence of such disintegration, are now considerably lessened. And that these rocks, anciently destroyed, contained most probably a far larger proportion of carbon and petrol than those of the same denomination now contain, since their disintegration took place at so early a period.

The seams of coal and their attendant strata must have resulted from the equable diffusion of the disintegrated particles of the primitive mountains carried down by the "gentle trickling of the numerous rills" and more widely diffused by more copious streams. The important sources of material for the coal beds were granite and trap, as those rocks contain natural carbon and hornblende, the latter mineral being an extremely important source. Kirwan's arguments are extremely ingenious and he finds no difficulty in explaining all known phenomena by means of his "supposition."

Playfair¹⁴ attacked Kirwan's doctrine and defended that of Hutton. He regarded Kirwan's suggestions as deserving only ridicule. He showed that both wood and mineral coal occur in the same bed and that most of Kirwan's postulates were not in accord with fact. The quantity of hornblende and silicious schist to be decomposed in order to yield the coal would be vastly greater than Kirwan had supposed; Playfair suggested that it would have been better to imagine that the diamond existed so abundantly in the primeval mountains as to constitute great rocks. A single ridge might suffice to give material for coal beds of all the surrounding plains. He asserted that Kirwan's hypothesis trespasses on every principle of common sense.

Voigt¹⁵ strenuously opposed v. Beroldingen's hypothesis that coal

¹⁴ J. Playfair, "Illustrations of the Huttonian Theory of the Earth," Edinburgh, 1802, pp. 148-160.

¹⁵ J. C. W. Voigt, "Versuch einer Geschichte der Steinkohlen, der Braunkohlen und des Torfes," Weimar, 1802, pp. 42-46.

beds originated as peat bogs. He believed that coal was formed chiefly from the harder species of reeds, and the vegetable matter had been dissolved in an oily substance. The fluidity of the material is proved by the occurrence of thin streaks in sandstone as well as by carbonaceous shale, which contains enough combustible matter to be utilized as fuel. The opinion that stone coal was at one time brown coal and that, in turn, originally peat deserves no consideration; it is merely the notion of a closet student and Voigt is surprised that Beroldingen, who had seen so many localities of stone and brown coal and peat, should offer the suggestion. Stone coal belongs to the oldest formations while brown coal and peat are of the newest; one might as well suggest that a child begat its mother, and the mother, the grandmother. It is sufficiently clear that Voigt conceived that the vegetable matter was first converted into bitumen and then transferred. His memoir was crowned by the Gottingen academy. The prominence thus given to it as well as the emphatic manner in which its assertions were made did much to repress the readiness shown by contemporaries to accept the Beroldingen hypothesis in whole or in part.

Faujas-St.-Fond¹⁶ discussing the source of coals occurring in what he terms granitic regions, says that they were deposited in bays or vast basins excavated by the sea. Currents transported into these receptacles materials from the granites, which became beds of greater or less thickness. Sometimes the seas brought the plants which, along with animals so abound in them, and these accumulated *pêle mêle* with the products of terrestrial vegetation brought down by the rivers. At other times the tides deposited on these beds of combustible materials the quartz sand of the sea bottom; at later periods, wood and plants arrived again, were deposited on the sands or clays; thus were formed the alternating beds of vegetable material with combustible residues of fish, mollusks and marine plants.

Al. Brongniart¹⁷ described in detail the various types of coal, lignite and peat. He evidently accepts Voigt's conclusion that there is no bond between coal and lignite, while at the same time he hesi-

¹⁶ B. Faujas-St.-Fond, "Essai de géologie," Paris, 1803, p. 443.

¹⁷ Alex. Brongniart, "Traité élémentaire de minéralogie avec des applications aux arts," Paris, 1807, t. 2, pp. 13, 14, 32, 36.

tates to accept the doctrine that coal is product of decomposition of organized bodies. Brongniart exhibits much caution in respect to generalizations but offers these conclusions which he thinks are derivable from actual observation: (1) That the coal is a formation contemporaneous with or posterior to the existence of the organized bodies; (2) that this combustible, when it was deposited or formed, was liquid, homogeneous and in a great degree of fineness, which is proved by the frequently parallelipedonous structure and by the manner in which it is absorbed by the beds which enclose it; (3) that the cause, which has deposited or formed it, was renewed several times in the same place, with conditions almost the same; (4) that this cause has been the same for almost all the earth, since the coal beds present in their structure and their accessory conditions almost always the same phenomena; (5) that these beds have been deposited without violent disturbances, since the organized bodies which are found in them are often entire and since the leaves, which are impressed on the shales covering the coal, are expanded and are hardly ever rubbed or even folded.

Parkinson¹⁸ regarded coal as a product of vegetable matter reduced to fluidity by bituminous fermentation; this fluid suffered modification of its inflammability by deposition of carbon and by intimate admixture with various salts. The vegetable matter had been swept into the sea by the universal deluge.

Kidd¹⁹ summarizes the doctrine of transport thus, "Powerful floods have swept away forests and subsequently covered them with the ruins of the soil in which they grew; whence those beds of clay and gritstone which so generally accompany the coal itself." His objections to this doctrine are that remains of trees and shrubs are wanting; that the plants are evidently those of many places; that the mechanical force, which uprooted the forests and swept away the vegetable matter as well as the greater amount of the earthy matter in the shales and gritstones, must have been extreme; yet the particles of the grit are not rounded and show no sign of attri-

¹⁸ J. Parkinson, "Organic Remains of a Former World," London, 1811, Vol. I., p. 248.

¹⁹ J. Kidd, "A Geological Essay on the Imperfect Evidences in Support of a Theory of the Earth," Oxford, 1815, pp. 126, 127, 128.

tion. He objects further that the theory does not account for the alternation of calcareous with argillaceous and siliceous beds, and asks on what principle one may expect that beds of earth spread out by the floods, should be periodically calcareous, argillaceous or siliceous, and how can it account for the alternations of clay beds with numerous coal beds; why should a second flood in its blind fury deposit a second series of beds on exactly the same spot where the first series is deposited?

Conybeare²⁰ adhered to the belief that vegetable matter alone was the source of coal and accepted Sternberg's suggestion that torrents tore off the vegetation from scattered primitive islands to deposit at the bottom of adjacent basins. He conceived at this early date a theory having not a few of the features characterizing one offered at a much later date. He thinks that the coal measures were deposited in estuaries and that the partial filling up of lakes and estuaries offers us the only analogies in the actual order of things with which the coal deposits can be compared. Respecting the deposit at Bovey Tracy, he says:

We must here suppose the wintry torrents to have swept away a great part of the vegetation of the neighboring hills and buried them in the estuary with the alluvial detritus collected in its course; the latter would, from its gravity, have sunk first and formed the floor; the wood would have floated till, having lost its more volatile parts by decomposition and become saturated with water moisture, it likewise subsided upon them, being perhaps loaded by fresh alluvium drifted down upon its surface; the re-iterated devastations of successive seasons must have produced the repetition and alternation of the beds . . . and if we suppose a like order of things to have operated more extensively and for a longer period during the formation of the coal strata, we shall find such an hypothesis sufficiently in accordance with their general phenomena.

Ad. Brongniart,²¹ after long study of the fossil plants, concluded that in the Carboniferous time the dry land was confined to islands on which grew the plants whose remains are in the coal formation. Numerous proofs established that the plants grew in the very places where they are found or, at most, within only a little distance away.

²⁰ W. D. Conybeare, "Outlines of Geology of England and Wales," London, 1822, pp. 334, 345, 347.

²¹ Adolphe Brongniart, "Prodrome d'une histoire des végétaux fossiles," Paris, 1828, pp. 183, 184.

The manner in which the plants are preserved in rocks accompanying coal beds as well as the presence of vertical stems in normal position are most convincing. He cannot attribute the formation of coal beds to accumulation of vegetable detritus transported from a distance and deposited in the condition of pulp (*bouillée*) as was supposed by Sternberg and Boue. In fact it would be difficult to understand how the causes, which reduced to a kind of pulp the plants which have formed the coal itself, failed to change the plants found in the neighboring beds; how it is that the coal formed in the sea contains no marine debris; how, finally, a substance thus deposited shows no more inequalities in thickness of the bed. He accepts De Luc's conception of vast swamps as best agreeing with observed conditions. The intervening rocks originated during periods of elevation of the sea-level or depression of the land.

Ure²² could not believe that coal beds are the remains of up-rooted forests or shattered trees. Reeds and ferns afforded most of the material and they grew not far from the place where the coal is found, as is shown by the state of preservation. The vegetable matter was reduced to a pasty condition, elaborated in the tepid waters of the primeval globe and was deposited in a semi-fluid condition where now found. The proof of this hypothesis is found in the great extent of very thin coal beds, the parallelism of the opposite faces, in the existence of narrow fissures filled with coaly matter, as well as in the homogeneous substance and texture and the cubical division in coal beds. The conversion of the buried matters into coal might continue ripening during many ages by percolation.

MacCulloch²³ devoted many years to actual investigations in both field and closet, the results being given in numerous brief papers. The outcome of his completed studies is presented in an elaborate discussion of the origin of coal and the formation of coal beds.

Peat, lignite and coal form a continuous series, the transition being sufficiently perfect. The character of the plants, the presence of tree trunks, their bark converted into coal, show that the plants from which coal was formed were terrestrial, not marine. Those

²² A. Ure, "A New System of Geology," London, 1829, pp. 163-174.

²³ J. MacCulloch, "A System of Geology with a Theory of the Earth," London, 1831, Vol. II., pp. 311, 312, 336, 337, 339, 341, 359.

plants, being aquatic in type, grew in low moist forests in marshes on the borders of lakes or rivers. From the fact that peat occurs in only limited quantity within the tropics, he argues against the supposed tropical nature of the carboniferous plants. These embedded plants are so often in such state of preservation as to preclude the notion that they had been transported. MacCulloch's study of peat bogs led him to recognize four types. Marsh deposits are vast in area, uniting on one side with Lake deposits and on the other with Forest deposits, as they may be on either lowland or upland. They owe their origin chiefly to *Sphagnum palustre*. Two sets of plants aid in forming the lake deposits; shallow portions of the lake give floating plants, which, after flowering, sink to form a vegetable stratum; other plants fringe the pond, detain clay and detritus, supporting reeds and bulrushes; these gradually advancing form a marsh and eventually the lake is filled. The Forest peat contains submerged wood and is produced, for the most part, by plants after fall of the forest, so that it is a marsh peat. It is always forming in forests and the submerged tree-trunks are almost wholly in one direction, having been overthrown by the wind. Maritime peat is formed in estuaries by *Zostera marina*, which causes formation of sandbanks and bars; seaweeds may contribute even to shore peat, for *Fucus serratus* and *F. nodosus* are found in deep peat at some places in Holland. Transported peat is rare, occurring only in small quantities and as a fine powder; it is due to bursting of bogs. MacCulloch, after a detailed comparison of phenomena observed in peat bogs with those observed in coal deposits, concluded that by far the larger part of the coal deposits are now lying where the progenitor plants grew.

Mammatt²⁴ appears to have been the first to recognize that an underclay usually accompanies coal beds. "Seams of fireclay abound in the Ashby coal-field and there are very few coal-measures which do not rest upon it, as the sections will show." He remarks further: "From the circumstance, that so many cases occur, where a tolerably pure fireclay lies immediately under, and in contact with, a bed

²⁴ E. Mammatt, "Coal Field of Ashby de la Zouche," 1834, p. 73. Cited by H. D. Rogers, Assoc. Amer. Geol. and Nat., Boston, 1843, p. 454.

of coal, it may be inferred, that such clay stratum could not have been the soil, where grew the vegetable matter which produced the coal, unless this vegetable matter was a moss, a peat, or some aquatic plant; because in the clay, there is no appearance of trunks, or other vegetable impressions, beyond slender leaves, as of a long grass."

Lyell²⁵ about this time committed himself in part to both hypothesis, though evidently disposed to favor that of transport. "The coal itself is admitted to be of vegetable origin and the state of the plants and the beautiful preservation of their leaves in the accompanying shales precludes the idea of their having been floated from great distances. As the species were evidently terrestrial, we must conclude that some dry land was not far distant; and this opinion is confirmed by the shells found in some strata of the Newcastle and Shropshire coal-fields." The alternation of marine limestone with strata containing coal beds may be due to alternate rising and sinking of large tracts, which were first laid dry and then submerged again. He is clearly inclined to agree with the suggestion made by Sternberg and Ad. Brongniart, that the beds of mineral detritus were derived from waste of small islands arranged in rows and he thinks that the suggestion is supported by the observation that the Coal Measures flora is of insular type.

At a later period, Lyell accepted the autochthonous origin of the coal beds, as appears in the "Travels in America."

Buckland,²⁶ in 1836, accepted the theory of transport. "The most early stage to which we may carry back its origin was among the swamps and primeval forests, where it flourished in the form of gigantic *Calamites* and stately *Lepidodendra* and *Sigillariæ*. From their native bed, these plants were torn away, by the storms and inundations of a hot and humid climate and transported in some adjacent Lake or Estuary or Sea. Here they floated on the waters, until they sank saturated to the bottom, and being buried in the detritus of adjacent lands, became transferred to a new estate

²⁵ C. Lyell, "Principles of Geology," 5th ed., 1st Amer. ed., Philadelphia, 1837, Vol. I., p. 134.

²⁶ W. Buckland, "Geology and Mineralogy considered with Reference to Natural Theology, Philadelphia, 1837, pp. 362, 353, 354.

among the members of the mineral kingdom. A long interment followed, during which a course of Chemical changes, and new combinations of their vegetable elements have converted them to the mineral condition of Coal."

On an earlier page, Buckland referred to the existence of erect stems in the Coal measures rocks: he was convinced that none of those recorded, aside from some near Glasgow, could have grown where they were found.

From this date onward the discussion respecting erect stems, became increasingly important. The facts and the conclusions are alike contradictory. It is better to pass by this matter for the present and to treat it apart.

Sternberg²⁷ did not accept the hypothesis that coal was formed from peat. He thought that one should conceive of a forest in the ancient time, when neither man nor plant-eating animals existed; that this forest grew for an indefinitely long period in a warm, humid climate; that the offal of buds, leaves, seeds, fruits and decayed stems accumulated on the ground; many generations of plants grew, one on the other, and so a mass, consisting of mold from wood, fruits, seeds, leaves, with complete examples of smaller plants, would be produced, whose surface would be covered with still living vegetation. Conceive now of a cataclysm, when a hurricane casts down the living plants and is followed by a flood, loaded with sand and mud—thus one has a true picture of the mode in which the overlying deposits of the stone coal are formed. Cases are rare where one finds erect stems of trees between two coal beds, losing themselves above and below in the coals.

The water-cover would hold the mold in place, would bring about decompositions and changes in the different materials and would cover the whole with clay and sand. It is unnecessary to borrow carbon from the air or water in order to get a coal formation, since in this interval, as well in the dry as in the wet way, humus and other acids, bitumen and coal itself have been produced, as occurs even to-day in peat bogs. The material existed in abun-

²⁷ K. Sternberg, "Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt," Siebenstes und achttes Heft, Prag, 1838, p. 88.

dance and fermentation necessarily followed under the covering of water and sediment. It is unimportant to determine whether the water was fresh or salt.

In this way, he sees no difficulty in accounting for accumulation of stone coal deposits, even those of Saint-Etienne, which are 60 fathoms thick. He emphasizes the fact that the particular vegetation of the stone coal period produced colossal stems.

Link²⁸ was the first to study the texture relations of coals. He observes that two theories had been offered to account for the origin of coal beds; that of driftage does not commend itself to him, but that referring the coal beds to ancient peat bogs appears more reasonable. After summarizing the opinions of v. Beroldingen, de Luc, Steffens, Hutton and Leonhardt, he presents the results of his own investigations. Von Buch, feeling perplexed by some recent publications, had given him some specimens of coal from Bogota and had asked that he study them microscopically. The composition of one of those coals so resembled that of peat that he was led to a wide study of coals and peats from several horizons and regions.

In all peats, whether loose or compact, cell tissues form the body of the mass; the difference in quality of the peats being due probably to difference in the plants; the stone coals resemble peat in structure, some recalling the comparatively loose *Linum* peat used as fuel in Berlin, while others are more like the dense, almost wood-like peat from Pomerania; the Mesozoic coals vary, one from the Muschelkalk closely resembles peat, but the Liassic coals appear to be composed largely of woody fiber; the brown coal of Greenland is like the *Linum* peat, while that of Meissner in Saxony is similar to the dense Pomeranian material.

Link observes two quarto plates illustrating the vegetable structures observed in each of the peats and coals examined.

Logan's²⁹ notable memoir on underclays appeared in 1841. He

²⁸ H. Link, "Über den Ursprung der Steinkohlen und Braunkohlen nach mikroskopischen Untersuchungen," *Abhandlungen d. k. Akad. d. Wiss. Berlin*, 1838, pp. 33-44.

²⁹ W. E. Logan, "On the Character of the Beds of Clay Lying Immediately below the Coal Seams of South Wales," *Proc. Geol. Soc. London*, Vol. III., pp. 275, 276.

had found almost one hundred coal beds in the South Wales coal-field and, with rare exceptions, each overlies a clay bed from six inches to ten feet thick. The clay varies much in composition but it is a persistent deposit, so that coal beds which have thinned out in the workings have been found again by following the clay. Ordinarily, *Stigmaria* occurs abundantly in the clay and Logan thinks that plant was the source of most of the coal.

Soon after the field work of the Virginia and Pennsylvania surveys was completed, H. D. Rogers³⁰ gathered the salient facts bearing upon the origin of coal beds and presented them in a paper which has become classical. It bears the impress of the time, but it was based on broad observations by the author and his equally celebrated brother, William B. Rogers, aided by a corps of able assistants; the studies, lasting six years, were in detail for an area of somewhat more than 20,000 square miles, but in addition less detailed studies had been made in Ohio and Kentucky, so that the region under consideration was not far from 40,000 square miles. The discussion was the first serious attempt to account for the origin of the Coal Measures, which was based on actual study of a vast area.

At the outset, Rogers pronounced against any theory of delta formation, as according to his belief the Appalachian ocean deepened toward the west and northwest.³¹ The deposits are traceable coastwise for 900 miles, so that it seems improbable that fluvial currents could have assembled them.

The sandstones decrease in thickness and coarseness as they recede from the ancient shoreline at the east; the shales increase in that direction for a time and then decrease, while the limestones, wholly wanting near the shore line, increase in thickness and purity so as to become imposing before the Ohio River has been reached. The animal remains found in the limestones are marine. There

³⁰ H. D. Rogers, "An Inquiry into the Origin of the Appalachian Coal Strata, Bituminous and Anthracitic," Reps. of Amer. Assoc. of Geologists and Naturalists, Boston, 1843, pp. 434, 459, 463-467.

³¹ It should be noted here that when Rogers wrote the conditions on the west side of the Appalachian basin were not known; but does not affect the general argument.

were many alternate periods of movement and of total or comparative rest. Limestones indicate periods of comparative tranquillity. Some of the coal beds are of great extent. The Pittsburgh bed had been traced around an area of 14,000 square miles and there are isolated basins holding that bed far southeast from the main area, so that the Pittsburgh coal must have covered a surface of not less 30,000 square miles. The uniformity in thickness and the absence of abrupt variations are as remarkable as the area. These features "seem strongly adverse to the theory which ascribes the formation of such deposits to any species of drifting action."

The alternation of laminae of bright and dull coal; the lenticular form of the bright layers; the predominance of mineral charcoal in the dull laminae seem to be almost conclusive arguments in favor of belief that the vegetable matter grew where it was deposited. He finds it difficult to understand why the coal does not consist principally of the larger parts of trees if any drifting agency brought the materials together. The leaves and smaller parts would be detached before the trunks could become waterlogged.

But the beds have subordinate divisions, coal, clay, impure coal, so persistent in great areas that miners can recognize their bed at great distance from their own locality; only one method of accumulation can explain this. "I cannot conceive any state of the surface, but that in which the margin of the sea was occupied by vast marine savannahs of some peat-creating plant, growing half immersed on a perfectly horizontal plain, and this fringed and interspersed with forests of trees, shedding their offal of leaves upon the marsh. Such are the only circumstances, under which I can imagine that these regularly parallel, thin and widely extended sheets of carbonaceous matter could have been accumulated." The purity of the coal is inconsistent with any notion of drifting of the vegetable matter, "which according to any conceivable mode of transportation, would be accompanied by a large amount of earthy matter, such as abounds in all delta deposits and even mingles with the wood as in the raft of the Atchafalaya."

The underclay, irregular in structure, accompanies nearly every coal bed in the Appalachian basin and usually contains *Stigmaria*

ficoides with its fibrous processes. The roof contrasts with the underclay and is, normally, a laminated shale due to more or less rapid current and it contains vast numbers of plant impressions.

When the roof is sandstone there is evidence of tempestuous currents and the vegetable fragments are trunks and stems of large plants. Occasionally limestone forms either roof or sole of the coal bed but there is usually a very thin layer of calcareous shale parting them.

No hypothesis, thus far presented seemed satisfactory to Rogers, and he presented his own to account for origin of the Coal Measures.

He imagined extensive flats bordering a continent, the shore of ocean or bays, beyond which was open sea. The whole period of the Coal Measures was characterized by a general slow subsidence of the coasts, interrupted by pauses and gradual upward movements of less frequency and duration, and these merely statical conditions alternated with great paroxysmal displacements of the land. During gentle depression, the coast was fringed by marshes while arborescent plants were on the land side. The meadows would give pulpy peat; leaves blown in or moved by higher tide would rest on the peat; some would be buried and become pulpy, or, in some cases, by rapid removal of volatile constituents would remain as mineral charcoal. An earthquake comes. Water is drained from the swamps and their tributaries; muddy water draws from swamp and swampy forests leaves and the rest to distribute them with the mud over the bog. This is the laminated shale. The sea returns, rolls over the swamp to the dry land; withdrawing, it brings uprooted trees, and washed off soil, strewing the land stuff in a coarse promiscuous stratum. Repeated waves would add to the mass. The disturbance ends; coarse materials sink, then the less coarse and last of all the finest sediment, light vegetable matter and the buoyant stems of *Stigmaria*, would sink together. A new marsh would be made and once more the savannahs would be clad with vegetation. This he terms the paroxysmal theory.

Petzholdt³² found two questions involved in the problem; were coal beds formed during a brief period and were they formed *in situ*

³² A. Petzholdt, "Geologie," Zweite Auflage, Leipzig, 1845, pp. 413-417.

or from transported vegetable material. The answer to the first question is certain—a great period of time was required for formation of the coal beds and their associated strata; but the second question is more complex and he is inclined to believe that both methods are possible, though there may be difficulty in determining which prevailed at a given locality. Vertical stems are not decisive, for they are found at times in rocks formed by transport, while prostrate stems occur in deposits clearly made *in situ*.

He believed that there were no continental areas during Carboniferous times, that the dry land consisted only of islands. For this reason, it is impossible to accept the hypothesis that coal was formed in great lakes or at the mouths of rivers. The only method of formation by transport would be the driving of great masses of vegetable matter against an island, which would collect in the quiet eddy on the opposite side, where, becoming waterlogged, they would sink and be covered with mud. He clearly prefers the doctrine of origin *in situ*.

An island, heavily forested for an indefinitely long period, becomes covered by a mass of bark, wood, etc., and similar remains of small plants. If the island be flooded by the outburst of granite and consequent elevation of the sea-level, the vegetation will be prostrated. By frequent outbursts the sea-level will be raised permanently and the island remains submerged. Deposits of sand and mud bring the island again to the surface of the water; a new forest rises on the grave of the old one. He thinks the alternation of strata and the formation of coal *in situ* can be explained very simply in this way.

Murchison,³³ after his study of the Donetz field in Russia, was convinced that the doctrine of transport alone could explain the conditions. The sections in southern Russia show "that the hypothesis of the formation of coal beds by masses of vegetation which there grew having subsided *in situ* (the truth of the application of which to some basins we do not deny) cannot be applied to the cases in question any more than to the pure marine coal beds of the northern districts, Northumberland and the northwestern parts of York-

³³R. I. Murchison, "The Geology of Russia in Europe and the Ural Mountains," London, 1845, Vol. I., pp. 112-114.

shire, etc.” Limestones with marine fossils are found at various horizons in the Donetz section. The presence of an underclay proves nothing—even though *Stigmara ficoides* be the only plant present for a confused assemblage of plants is seen above and below the coal beds and the fossil beds are exclusively marine. The fine underclay indicates only that the sea bottom was covered with detritus of plants washed in by floods; the heavier earthy matters, accompanying the detritus, sank to the bottom, while the plants floated and formed the upper stratum. Those plants, thus left on the muddy slime, were covered afterwards by other sediment. Much of the coal, in strata alternating with marine sediments, may have come from the washing away and sinking into the sea of floating masses of matted earth and plants.

At a later date,²⁴ he discussed the question more broadly. He refers to the terrestrial conditions exhibited in the Upper Carboniferous of England and to the lack of a physical break there between the Lower and the Upper Measures, such as appears in Germany and France. In those countries, the later accumulations may well be accounted for by depressions of low woodlands and jungles beneath freshwater, followed by elevations and depressions. There is no physical break in Britain, but there is the same passage from marine to terrestrial conditions, of which the coal beds offer positive evidence; for the roots of *Sigillaria* are found in the underclay, which was the soil of a primeval marsh or jungle. The view, which supposes many and successive subsidences of vast swampy jungles beneath the level of the waters, best explains how the different organic masses became so covered with beds of sand and mud, as to form the sandstone and shale of such coal fields. But this theory of oscillations . . . can scarcely have an application to those other seams of coal, which, as before mentioned, are interstratified with beds containing marine shells, the animals of which, such as *Producta* and *Spirifers*, must have lived in comparatively deep water.”

He conceived that the latter class is to be explained only by the supposition that great rivers, flowing through lowlands, transported vast quantities of trees, etc., entangled in earth, and de-

²⁴ “Siluria,” 3d ed., London, 1859, pp. 315-317.

posited them on the bottom of the estuaries, or that vast heaps of organic matter were carried as floating masses to the sea. The Northumberland deposits, large tracts of Scotland, as well as the Donetz field in Russia offer fine proofs of these conditions. There were at least two modes in which coal measures were formed, one terrestrial, the other subaqueous.

Goeppert²⁵ in his elaborate work on the formation of coal beds gave the results of many years of study in the Silesian coal fields. A large part of the volume is devoted to determination of the materials forming coal; it will be considered in another connection. The chapter on the formation of coal beds is supplemented by a mass of illustrations drawn from the coal fields of Silesia, the whole discussion being so compact, so free from unnecessary detail that to make a just synopsis is difficult. The standpoint in Goeppert's work differs much from that in the discussion by Rogers, the only preceding study with which it can be compared. Rogers knew little about the intimate structure of coal itself and reasoned wholly from stratigraphical conditions; Goeppert was a skilfull palæobotanist as well as stratigrapher.

The important question for Goeppert is, were the coal beds formed of plants growing in place or of plants brought in from other localities.

There were many islands, mountains, valleys, rivers, etc., in the Coal Measures time. The organic matter was deposited on plains which were covered with sand, clay or mud. The extent of the deposits, their occurrence as plains or as basins show that they were laid down on the sea-bed, on slowly changing coasts or in enclosed sea or lake basins. The few marine products found in coal beds do not favor the opinion that the coal-forming material was collected from distant places and deposited in the depths of bays; everything indicates the utmost quiet; the vegetation covered

²⁵ H. R. Goeppert, "Abhandlung eingesandt als Antwort auf die Preisfrage—'Man suche durch genaue Untersuchungen darzuthun, ob die Steinkohlenlager aus Pflanzen entstanden sein, welche an den Stellen, wo jene gefunden werden, wachsen; oder ob diese Pflanzen an anderen Orten lebten, und nach den Stellen, wo sich die Steinkohlenlager befinden, hingeführt wurden?'" Amsterdam, 1848, pp. 119-131, 136-139, 141-160, 278, 279.

the low-lying horizontal sea-strand. Changes of level, elevation and subsidence, led to burial of the plants under the ocean; sand and clay were deposited on the plant covered surface; dunes were formed, on which plants grew to run the same course. Through repetition of this process, the different beds were formed, separated by sand and clay. The conditions were like those of the present day, for submerged bogs and forests have been observed at many places along the coasts of Europe and America.

Well preserved stems are wanting because the plants lacked a dense interior structure. Filled stems are rare in Tertiary deposits because the trees were dicotyledonous; whereas they abound in the Coal Measures because the loose interior structure decayed quickly. Plants grew in these hollowed stumps; Goeppert found *Lepidodendron*, *Calamites* and ferns in decayed *Sigillaria*; in the stump of *Lepidodendron* he found the stem of a new genus, two feet long and vertical.

If the coal had become compact or if the quiet were undisturbed, the boundary between coal and the succeeding deposit is sharply defined; at most one finds only impressions of stems lying upon the upper surface. This latter condition occurs frequently in Upper Silesia, where the coal is composed chiefly of *Sigillaria*. It is quite true that filled stems occur even within the coal itself; Goeppert found them. He explains their presence by supposing that clay and sand were brought down by floods before consolidation of the coal, before the spaces between the stems had been obliterated by compression. In the same way he accounts for Brandschiefer or bituminous shale; the influx of muddy waters caused the alternation of laminae of bright coal, containing 2 percent of ash, with dull layers, containing much mineral charcoal and 20 to 25 percent of ash.

The overlying beds were deposited after complete formation of the coal bed and the time-interval between the two deposits is as variable as the intervals interrupting the formation of a coal bed itself. Partings in coal beds show how the time required for different types of deposits may vary. A parting, ten inches thick, may be equivalent in time to a sandstone deposit elsewhere, many fathoms

thick. Perhaps one may regard layers containing great abundance of plants as equivalent to deposits in which the plants do not form beds, because in the latter case the plants were brought in contemporaneously with the sand and mud masses. He is convinced that the coal and the enclosing sandstone or shale beds are wholly independent deposits. And this belief is strengthened by the fact that the material, filling stems in coal, clay or sandstone, differs from that which surrounds them—an additional evidence of the extreme quiet prevailing during deposition. Goeppert was the first to recognize that the coating of the filled stems is the converted bark. The roots of *Sigillaria* and *Lepidodendron* were feeble, as are those of related plants to-day, and the trees were overthrown easily; and thus it happens that the stems, as in Upper Silesia, contribute to the formation of the coal. When overthrown, their cellular interior was squeezed out and converted into coal, as is seen near Dombrowa. All the phenomena indicate that the coal deposits were made during conditions of quiet, which would be impossible unless the plants grew where the coal is found.

The vast extent and constancy in structure exhibited by coal beds is important. He cannot think that such a mass could be floated in at once, yet how could it be deposited so regularly by any other means? He agrees with Lindley and Hutton and with Burat that the mass is too great for transport. He is unable to believe that the coal was the product of forests, because the amount is so vast; but the evidence satisfies him that the plants have not come from a distance. He prefers to accept the opinions presented by v. Beroldingen, De Luc, Ad. Brongniart, Link, and to believe that, if not all coal beds, at least the thickest originated as peat bogs—the more so because of the resemblance which a buried peat bog has to a coal bed.

He conceives that on the damp floor there grew lycopods, calamites, ferns, stigmaria and other plants, corresponding to the cryptogams and monocotyledons of present day bogs. Tree-like *Sigillaria* and *Lepidodendra* grew on the borders of the bog and at times were uprooted by floods. He laid great stress on the preservation of the plants, as precluding the possibility of transportation; he finds the mode of decay of tree stems equally important, for the conditions observed in *Calamites* are the same with those found in his experi-

ments with *Arum*. The presence of vertical stems is noteworthy because they are so numerous. It is possible for floods to carry away whole trees and to deposit them in vertical position; that occurred in the great débâcle near Martigny in Switzerland. This explanation would suffice for an isolated instance; but the number of such stems in the Coal Measures is too great; the analogy is in submerged forests of our own day.

The distribution of plants, both vertically and horizontally, has an important bearing on the subject. At one locality the flora may consist almost wholly of one species and at another, almost wholly of another species. There is a group-like distribution, so to speak, a social occurrence. In Upper Silesia, the coal may be termed *Sigillaria* coal, while in Lower Silesia it is *Stigmaria* coal. He asserts that an observer, in viewing the coal bed, involuntarily thinks of a peat bog.

Lyell's volumes on his second visit to the United States appeared at this time and had material influence in moulding public opinion. They will be cited in another connection.

Naumann²⁸ recognized the distinction between deposits formed on the sea border and those in fresh-water lakes, as had been done by Elie-de-Beaumont and Burat. The former contain, especially in their lower portions, rock layers with organic remains corresponding to the marine mode of formation, while the latter, less extensive, have no traces of marine fossils or anything else to show co-working of the sea. These types he terms *paralisch* and *limnisch*. These terms are equivalent to pelagic and mediterranean of Elie-de-Beaumont, to *terrains houillers de haute mer* and *terrains houillers des lacs* of Burat. The coal deposits of Great Britain, Belgium, Westphalia, Russia and America are *paralisch* or pelagic; those of central France, Saxony and Bohemia are *limnisch* or lacustrine.

The prevailing rocks of the Carboniferous are conglomerate, sandstone and clay shale, which occur in *paralisch* and *limnisch* alike. They are derived mostly from destruction of other rocks and their materials were transported. The land consisted not of small low-lying islands but mainly of great islands and continents

²⁸ C. F. Naumann, "Lehrbuch der Geognosie," Leipzig, 1854, Vol. II., pp. 451, 452, 571-580.

with mighty rivers, along whose coasts and in basin shaped depressions was deposited the vast system of sand and mud strata: This at length became marshland, offering the ground for the luxuriant vegetation of the first coal bed. In the Appalachian region, there may have been the flat coast of a land extending far to the east, from which great rivers carried sand and mud into the shallow sea at the west, in which, farther away, limestone was forming. Processes such as those now seen in the Nile, Mississippi, Hoangho and other rivers, continuing for many thousands of years, would raise the sea bed until it reached the water surface as a wide-spread marshland. Similar operations were going on in freshwater basins of the dry land leading to the formation of morasses, supporting *Calamites*, *Sigillaria* and other Carboniferous plants, which would give a deposit of peat.

The alternation of a great number of coal beds with thick masses of sandstone and shale is not so easily explained as is the origin of the first coal bed. The causes in paralisch areas are different from those in limnisch basins.

Lyell, Lindley and others held the opinion that seacoasts, on which paralisch deposits were formed, underwent slow subsidence during Carboniferous time. If one suppose that this subsidence was interrupted periodically, we have a mechanism by which the formation of successive coal beds could be explained. A similar result would be secured by occasional elevations of the sea-bottom, according to Petzholdt's conception. There is necessary in each case a general rise of the sea-level to cover the plant deposit with the sandstone and shale needed to give another swampy surface. This alternating subsidence and stability of the sea-bottom explains why the shale, covering coal beds, encloses a mass of plant remains and also why paralisch territories may have many but thin coal beds.

This explanation is not wholly satisfactory for limnisch areas, since one can hardly suppose that all of those could have suffered the repeated subsidence. One must conceive that between longer periods of stability there were epochs in which increased fall of inflowing streams or a diversion of flow occurred. The greater carrying power of the streams would bring the plant deposit and

at length form a new surface on which vegetation would begin once more. This would give a smaller number of beds. The, at times, great thickness and the frequent irregularity of coal beds in limnisch areas may be explained in part by supposing that they were not formed wholly as peat deposits, but received masses of upturned vegetation, swept out by floods, and this leads to the question of the formation of a particular coal bed.

There are two theories, transport (*Anschwemmung*) and *in situ* (an Ort und Stelle). Both may be correct. The great beds, beyond doubt, are of *in situ* origin, but there are many deposits which can be explained only by transport of plant masses.

It is known that streams bring down astonishing quantities of plant material; that ocean currents carry driftwood far and that it accumulates in vast masses on shores. Currents of the olden time must have been similar. If the widespread masses were buried under sediments, they would be transformed into coal beds. Neumann thinks that repetition of this process at mouths of streams in lakes or on the sea-coast would give a system of strata like the present series of coal beds with intervening sandstones and shales. Such drift masses are irregular in extent and thickness, often as blocklike masses. Such transported material would give conditions like those observed in coal beds of some limnisch areas, great irregularity and variation in thickness, breaking up into separate benches, some of them excessively thick. He thinks that under especially favorable conditions a coal bed might be formed in this way which would resemble one formed *in situ*. He considers also that this theory of transport explains many regular coal beds, such as those between limestones or other strata distinctly marine, as well as beds resting directly on granite, limestone, etc., without an underclay. He agrees with Murchison that in some cases the transport theory has value.

But for the greater part of the coal beds, the *in situ* theory must be accepted; their material was produced by vegetation an Ort und Stelle. All beds continuous over great areas, with regular and not too great thickness and with a *stigmaria*-filled underclay are to be explained in this way. But one must not think that there were real forests, which were thrown down in place, compressed by in-

coming sediments and changed into layers of plant material. The Carboniferous was not a tree and forest flora; it was morass and strand vegetation, developed on great emerging plains of marshland. The prevailing forms suggest that formation of the widely extended coal beds was analogous to the formation of peat bogs.

The purity of coal substance, the continuity of the beds, their regular thickness, the arrangement in benches due to clay layers produced by inconsiderable inundations, the upright plant stems and all the remaining relations of most coal beds appear to find sufficient explanation only in this or a similar conception of the mode of their formation. When at length a permanent elevation of the sea-level comes, the bog is buried under sand and mud, in whose first layers, just as in the last conditions of peat vegetation, a great mass of plant remains is found, torn from the neighboring land; so that it is clear that the roof shale of a coal bed encloses as a rule a large number of isolated plant remains.

Newberry's⁸⁷ attention was attracted to the cannel and semi-cannel of Ohio at the beginning of his studies. Observations made in peat bogs of this country and Europe led him to believe that cannel was formed in lagoons, where completely macerated vegetable tissue, probably parenchyma for the most part, accumulated as vegetable mud. Among other arguments favoring his hypothesis, he urges that cannel is more nearly homogeneous than cubical coal; that it contains more volatile matter, with more hydrogen, and must have been deposited in a hydrogenous medium which prevented oxidation; that it contains aquatic animals, so abundant at times, as to prove that they inhabited pools in which cannel was a sediment; that the plant remains in cannel are usually skeletonized; and that in open water lagoons of modern peat marshes, fine carbonaceous mud accumulates, which when dried is very like cannel.

Le Conte⁸⁸ compared the peat bog and estuary theories. The arguments in favor of the peat bog theory are, the purity of the coal, the fine preservation of the tender and more delicate parts

⁸⁷ J. S. Newberry, *Amer. Journ. Sci.*, 1857. A synopsis of this paper with some additional notes was given by him in *Geol. Survey of Ohio*, Vol. II., 1874, p. 125.

⁸⁸ Joseph Le Conte, "Lectures on Coal," *Ann. Rep. Smithsonian Inst. for 1857*, Washington, 1858, pp. 131-137.

of plants, the position of these plants in the roof shale, the completely disorganized condition of materials in the coal, the presence of the underclay, with roots and the occurrence of vertical stems rooted in the underclay. The chief objection to the theory is the repeated alternation, in the same locality, of coal seams with marine and freshwater strata. There being as many as one hundred coal seams, it would appear as though the same spot has been raised above water level and had been depressed below it at least one hundred times.

The estuary theory was proposed to avoid this difficulty. As an estuary at the mouth of a great river is occupied now by salt- and again by fresh-water, it should contain alternating deposits of marine and fresh-water origin. In seasons of freshet, the salt water is pushed out and the river water, loaded with mineral detritus and timber rafts, makes its deposits; during low water, the sea returns and marine deposits follow.

Le Conte finds insuperable objections to the latter. He thinks that coal beds were formed as peat bogs at the mouths of large rivers. The analogy is to be sought, not in the bogs of Ireland, but in those of the Mississippi delta. He supposes a vast delta, with spaces protected by fringes of plants from influx of river muds. There pure vegetable matter would accumulate until during some violent flood the barrier would be broken down and the whole space covered by mud. The delta, like that of the Mississippi, subsided slowly and the covering of mineral detritus eventually became ground for a new marsh. If the subsidence were more rapid than the river deposits could overcome, the sea would take possession and limestone would be formed. There is no necessity for conceiving repeated upheavals and depressions. "Coal has almost certainly accumulated *in situ* in extensive peat swamps at the mouths of large rivers, upon ground which was slowly subsiding during the whole period."

Lesquereux,³⁹ after long study of peat bogs in Europe, came to the United States, where as palaeobotanist to several official sur-

³⁹ L. Lesquereux, Palæontological report on fossil flora of the Coal Measures, Third Ann. Rep. Geol. Survey of Kentucky, Frankfort, 1857, pp. 505-522.

veys, he examined coal beds within a large part of the Appalachian and Mississippi coal fields. His first report upon the work in Kentucky is prefaced by discussion of matters relating to the origin of coal beds as illustrated by conditions in the Appalachian basin.

Bog plants are partially immersed and ordinarily are woody. The trees are mostly resinous and are such as can thrive only in bog conditions. The Coal Measures plants are ferns, clubmosses, horsetails, reeds and rushes, in character much resembling the forms prevailing in modern bogs. The peat of the Great Dismal and Alligator swamps rests on white sand and fills the depressions, while its surface is covered by canes, reeds and shrubs; where there is a cover of water, the soft black mud supports cypress and magnolia, and a great mass of material is added each year. Some ponds were once covered with vegetation, now sunken, as in Lake Drummond, which has at its bottom a forest, probably carried down by its own weight. He found similar phenomena in Sweden, Denmark and Switzerland. The water, to permit formation of peat, must have a constant level and be stagnant. The clayey bottom of bogs was made by fresh-water mollusks and infusoria or by *Characeæ* and *Confervæ*. Peat always has this mud.

Comparing these conditions with those prevailing in the Coal Measures, Lesquereux finds: (1) The fireclay varies in thickness, color, composition and in the quantity of *Stigmaria*; sometimes no coal rests on it—the soil was ready but conditions did not favor accumulation. Yet fireclay, without coal at one place, is likely to bear coal elsewhere. (2) The coal varies abruptly in physical and chemical features, just as peat varies in all directions, horizontal and vertical; and these variations depend largely on the plants concerned as well as on the amount of foreign matter introduced. (3) The roof shales, usually very fine, are evidence of slow subsidence, sometimes without marine invasion, as shown by plant remains; sometimes with marine invasion, as where the shales contain shells of brackish water type. (4) The limestones, equivalent to or continuation of the shales, need quiet deep seawater. Influence of the sea is very distinct in erosions due to currents. (5) The sandstones were due in many cases to turbulent waters, as appears from the

erosions and the mighty erect trees. The sand may have been derived possibly from dunes such as those on the Rhine or Elbe.

Lesquereux knows of no peat composed of fucoids and marine plants.

Jukes's⁴⁰ contribution to the discussion is not less important than those by Rogers and Goepfert, as it is the first presentation of the transport theory based on careful observation in an extended area. It covered the ground so thoroughly that little aside from detail or local coloring has been added since its publication.

Two opinions exist respecting the origin of coal beds; the first is that trees and plants were drifted into lakes, estuaries and shallow seas, where, becoming waterlogged, they sank to the bottom and became covered by the other accumulations; the second is that the plants were not drifted but grew and perished on the spot where they have formed the coal, just as our peat bogs would form coal if long buried under a great mass of earthy matters. While he does not purpose to range himself as an advocate of either opinion, he finds difficulties in the way of the latter which make him hesitate to accept it exclusively. These, observed in the South Staffordshire coal-field, he gives in detail.

1. The "rolls," "swells" or "horsebacks," which are ridge-like accumulations of clay rising sometimes eight feet above the floor, cannot be explained if the coal were formed at or above the level of the water; but if coal and "swell" alike were formed under water no difficulty exists.

2. The "rock faults" in the Thick coal. These are of two kinds. One, which he has not seen, is due to erosion of the coal after deposit, the hollow being filled with the material deposited on the coal. The other comes from contemporaneous deposition of silt or sand with the coal, so that they alternate at short intervals. The coal encloses cakes, layers or masses of sandstone, more or less intermingled with it. One such "fault" seen by Jukes, was 286 yards wide and it had been followed 400 yards without reaching the end. The upper part of the coal bed passes over the sandstone. At the

⁴⁰ J. B. Jukes, *Memoirs*, Geol. Survey of Great Britain. "The South Staffordshire Coal-field," 2d ed., London, 1859, pp. 34-42, 44-49, 201-206. The writer has not seen the first edition, published at least ten years earlier.

lateral border, both coal and sandstone split up so as to interlace. The condition is precisely similar to a cake of sandstone in clay. Jukes asks, if the sandstone was deposited in water, why not the coal also, for they are interstratified. The partings of sand in coal beds are of the same type. The laminæ of coal are obviously laminæ of deposition; their arrangement and their alternation with films of shale or with thicker partings of clay or sand would all be explained by the gradual deposition of laminæ and strata of different kinds of substances and by different degrees of mingling at the bottom of some body of water.

3. The extreme bifurcation of some coal beds; and here are phenomena extremely perplexing from the standpoint of the *in situ* theory. The great bed near Dudley, known as the Thick coal, is composed of numerous benches, each with its own persistent peculiarities. At two miles north from Dudley there are eleven benches, with 36 feet 6 inches of coal and 2 feet 11 inches of partings; while at one mile east from Dudley, there are thirteen benches with 28 feet 7 inches of coal and 1 foot 9 inches of partings. But at two miles east of north from Dudley, the upper two benches, there known as the Flying Reed coal, are at 84 feet above the Thick coal; at two miles farther, the interval has increased to 204 feet, while an intercalation of 10 feet appears midway in the Thick coal below. The benches retain their distinctive features throughout. Similar conditions prevail toward the west, where the interval between the Flying Reed and the other portion of the Thick coal increases from almost nothing to 128 feet within barely three miles.

There is a higher bed known as the Brooch coal. It is 95 feet above the Flying Reed, where that bed is 10 feet 6 inches above the Thick; but where the latter interval becomes 115 feet, the former is only 30 feet. Thus, while the Brooch and Thick are rudely parallel, the Flying Reed is oblique between them.

The normal section persists in the central southern part of the field to some distance south from Dudley; but toward the southwest the Thick coal breaks up, loses its structure and becomes worthless; toward the southeast, the bed thins out, has little good coal and is troubled by "rock faults" or "cakes of sandstone."

An additional difficulty is found in the expansion of the Thick and other coal beds toward the north. The expansion of the whole series and the splitting of the beds in that direction seem incompatible with the idea that the coal beds were formed at or above the surface of the water, while the intervening strata were deposited under it. Of the intervening rocks, those of coarse material are heaped up usually and thin out rapidly in all directions, while those of fine material have a greater area. This is true of superimposed beds forming a group; when material is fine, the disappearance of a bed is gradual. This law of area and thickness means only that fine materials were spread over a larger area "in consequence of their comparatively light specific gravity, or at least of their being more easily and therefore more widely transported by water, and being more generally diffused through it before finally coming to rest at the bottom. It was pointed out before, too, that beds of coal so far from forming any exception to this general rule, are its most marked example at the one extreme, while coarse sandstones and conglomerates form the most striking example at the other. . . . I wish merely to say as the result of an experience of a good many years, confirmed by the particular instance under examination, that the phenomena of the lamination and stratification of beds of coal, and their interstratification and association with other stratified rocks are explicable *solely by the relation of the specific gravity of their materials to the action of moving water*, and the consequent diffusion of their materials through the mass of that water."

The materials of the clays and sandstones were most largely deposited on the northern side of the coal field and sometimes failed to reach the southern part of the area, whereas the coal beds "were diffused equally, or at least more equally, over the whole area." He finds in the Bottom coal bed a notable illustration of these conditions—and it is only one of many. One "cannot fail to be struck with the obvious 'delta-like' or 'bank-like' form which the Coal Measures of South Staffordshire must have originally possessed, and the perfect resemblance they must have had to an undisturbed subaqueous accumulation. It seems to me then impossible to suppose otherwise than that the whole series of the Coal

Measures, coals included, were deposited by one connected operation of the same forces acting in obedience to the same physical laws on similar but slightly differing materials, through an indefinite but immensely long period of time."

Dawson spent many years in investigation of the Acadian coal fields, but devoted his attention especially to the South Joggins region where exposures are almost complete in a section of more than 11,000 feet thickness. He visited that locality with Lyell in 1852 and 1853 and afterwards made detailed study of each coal bed as well as of each ancient soil, subjecting samples from all to careful macroscopic and microscopic examination. The results of his studies were given in several memoirs and the details were published in the second edition of "Acadian Geology." In his first elaborate memoir⁴¹ he called attention to the gradual passage from coal to the roof shales through laminæ composed of coaled leaves and flattened trunks, separated by clay. He expresses the opinion that erect forests explain to some extent the accumulation *in situ*. The sandstone casts of *Sigillaria* are enclosed in bark converted into caking bituminous coal, while remains of the woody matter remain as mineral charcoal at the bottom of the cast. A series of such stumps with flattened bark and prostrate trunks may constitute a rudimentary bed of coal, of which many occur in the South Joggins section. He is convinced that the structure of the coal accords with the view that it accumulated by growth and not by driftage and that accumulation was very slow. He regards *Sigillaria* and *Calamites* as the chief contributors to the formation of coal. The woody matter remains mostly as mineral charcoal, while the cortex and such other portions as were submerged gave the compact coal. This memoir is concerned, for the most part, with the origin of coal.

In a later memoir,⁴² he considered especially the subject of accumulation. After describing the formations and the physical condi-

⁴¹ J. W. Dawson, "On the Vegetable Structures in Coal," *Q. J. G. S.*, Vol. XV., 1859, pp. 638, 640.

⁴² "On Conditions of the Deposition of Coal, more Especially as Illustrated by the Coal Formations of Nova Scotia and New Brunswick," *Q. J. G. S.*, Vol. XXII., 1866, pp. 95-104.

tions observed in the numerous coal beds, he presents these conclusions:

(1) The occurrence of *Stigmaria* under nearly every bed of coal proves accumulation *in situ*; the sediments between the beds prove transport of mud and other materials, the conditions being those observed in swampy deltas. (2) True coal consists mostly of bark of *Sigillaria* and other trees, leaves of ferns and *Cordaites* with other débris, fragments of mineral charcoal, all grown and accumulated where they are found. (3) Microscopic structure and chemical composition of cannel and earthy bitumen as well as of the more highly bituminous and carbonaceous shales prove that they were fine vegetable mud as in the ponds and lakes of modern swamps. (4) A few underclays consist of this vegetable mud, but most of them are bleached by drainage. They contain not sulphide but carbonate of iron; rain, not seawater, percolated through them. (5) Most of the erect and prostrate trees had become hollow shells of bark before final embedding and their wood had been broken into cubical pieces of mineral charcoal; land snails, galley worms and reptiles were caught in them. There is much mineral charcoal on surfaces in all the larger coal beds. (6) *Sigillaria* roots have much resemblance to rhizomas of certain aquatic plants, but structurally are identical with cycad roots, which the stems resemble. *Sigillaria* grew on soils supporting conifers, *Lepidodendra*, *Cordaites* and ferns, which could not grow in water. There is remarkable absence of aquatic vegetation. (7) The occurrence of marine or brackish water forms is no evidence of sub-aqueous formation. The same condition is observed in the case of submerged forests.

The channels, sand or gravel ridges, inequalities of floor observed in coal beds are familiar features of modern swamps. The lamination of coal is not aqueous lamination; it is the superposition of successive generations of more or less decayed trunks and beds of leaves. It is very different from the lamination observed in cannels and in the carbonaceous shales.

The doctrine that coal is composed of the débris of land plants, though maintained by nearly all students, did not pass unchallenged. As far back as 1815, Parrott suggested that seaweeds had contrib-

uted materially to the formation of coal and, at a later date, Bischoff conceived that the Sargasso sea might yield a coal bed. Mohr,⁴⁸ in 1866, presented this view with great energy, and his opinions received more or less support from some eminent students.

Mohr contrasts stone- and browncoal, the one being fusible the other infusible. Land plants with much woody fiber yield charcoal, which soon decays when exposed to air and moisture. But seaweeds, river and lake algæ, having no fiber, decay to slime, which hardens through loss of CO_2 and CH_4 , the original composition being that of starch and the allied substances. He combats Bischoff's assertion that *Calamites* and other land plants were concerned in forming coal, for the mass of the coal is amorphous and no treatment gives trace of plant skeleton. Evidently, everything with recognizable structure is a foreign body. Coal did not originate from land plants but from water plants, whose growth is protected from air and decay.

Only one of these water plants, a grass of wide distribution, is a phaenerogam; the genera and species of the others are very numerous and their mass is inconceivable. The Sargasso sea alone has an area seven times as great as that of Germany and none of its material can escape. Here is ample material; contributions from land plants are only accessory. The ash from sea weeds contains no clay; that from coal, lignite and peat consists of silicates not belonging to plants and contains clay. This material is derived from land detritus. The ammonia in distillates from coal is of animal origin; no accumulations in landlocked basins could have animals enough to supply this ammonia, but Darwin and Meyen have described the vast numbers of mollusks and other forms attached to seaweeds.

Sea plants are swept away, decay and sink or are distributed by currents. They are heaped up to great thickness, there being 338 feet of coal in the Saarbruck basin. Darwin saw immense masses of seaweed, floating, so constant in position that they are mapped as reefs and sand banks. If a layer of leaf coal occur, it is evidence only of material brought in from the land. The absence of

⁴⁸ F. Mohr, "Geschichte der Erde," Bonn, 1866, pp. 82-100, 130, 137.

animal remains in stone coal is due to the solvent power of carbon dioxide coming from the decomposing seaweeds.

Muck⁴⁴ came strongly to support of Mohr's doctrine in the first edition of his work. The essential objections to the theory are: (1) That great accumulations of seaweed are not likely to reach the bottom; (2) that remains of seaweeds have not been found in dredgings, which bring up only inorganic materials and animal remains; (3) the poverty of earthy materials in stone coal; (4) the absence of sea plants, and (5) the rare occurrence of sea shells in stone coal.

The answers to these objections are:

That the first is based on supposition, originating in lack of knowledge; that, for the second, it may be well to wait for its invalidation by opposing facts; as for the third, it stands in close connection with the second and so may be of narrowly conclusive value, but it is to be remarked that the ash-poor glance coal alternates with the often very ash-rich matt- and cannel coal, whose ash does not proceed from beds intervening between the coals, but is so intimately mixed with the coal stuff that it can be due in only small degree to later infiltration; as for the fourth, absence of sea plants is explained by the fact that those plants, in dead or torn condition, with or without access of air, undergo decay very quickly, becoming, within a few weeks or months, a structureless mass, in which organic remains cannot be recognized; the fifth is answered very easily, for animal remains are calcareous and are removed by carbon dioxide which originates during the coal making process.

In the second edition of his work, Muck, though no longer urging the theory, argued that sea plants, embraced under the trivial term "Tang," offered and do offer enough material for stone coal formation. The disappearance of organic structure in stone coal is explained as easily for seaweeds as for land plants by a kind of peaty fermentation. The morphological differences between seaweeds and the land plants corresponds to chemical differences in composition.

Petzholdt⁴⁵ gave a more than halting adhesion to this doctrine

⁴⁴ F. Muck, "Die Chemie der Steinkohle," Leipzig, 1st ed., 1880; 2d ed., 1891. The citations are from the second edition, pp. 162-165, 168.

⁴⁵ A. Petzholdt, "Beitrag zur Kenntniss der Steinkohlenbildung," Leipzig, 1882, pp. 25, 26, 27.

though without mentioning Mohr in connection with it. Referring to the current opinion that the material for formation of coal may be wholly or at least in great part derived from land plants, he says that this is evidently pure hypothesis, for remains of undoubted land plants occur in coal only under exceptional conditions. As, at the time when stone coal and anthracite were formed, the land was sunken, it is doubtful if the then production of land plants could yield the vast quantity required for the coal beds, he is led to look elsewhere for suitable material—and that, the sea plants appear to have produced. Remembering that the fauna of the Coal Measure time was marine and that, for these vast numbers of genera and species, the nourishment could come only from algæ, he asks with Bischoff, "where are the remains of the vast masses of sea plants, which since the Plant Kingdom first appeared on earth, have grown and then perished?" He replies that they have been consumed in forming coal and anthracite beds; and he is compelled to admit the conclusion that algæ, not land plants, produced the chief material for coal-making. At the same time, he is careful to state that this is only hypothesis, without direct proof, since remains of algæ are as rare in coal as are those of land plants.

Mietzsch⁴⁶ devoted much space to discussion of this hypothesis, which he regarded as baseless. His objections are those tabulated by Muck in the work just cited. In the concluding part of his argument, he points out that the Challenger expedition crossed the ocean along several lines and that the results of dredging leave uncertain whether seaweeds, after death, reach the bottom, become decomposed at the surface or become covered with animal remains. The Challenger expedition found no seaweed on the way to coal, though, several times it crossed the area, where, if ever, such deposits might be expected. Not only the petrography of coal but also the palæontology opposes the hypothesis. Seaweeds have not been discovered and the forms known in earlier days as fucoids have proved to be land plants.

Lesquereux⁴⁷ referred to Mohr's hypothesis only to reject it.

⁴⁶ H. Mietzsch, "Geologie der Kohlenlager," Leipzig, 1875, p. 244.

⁴⁷ L. Lesquereux, Ann. Rep. 2d Geol. Survey of Penn. for 1885, p. 104. Same for 1886, p. 465.

Seaweeds have cellular structure alone. They decompose quickly whether exposed to atmospheric oxygen or protected from it. They are soon transformed into a fluid, black material which penetrates the sands along the seashore. He thinks it possible that remains of marine algæ may have been thrown casually on swamps and that their decomposition products, added to those of the decomposing materials, may have enriched them and may have given cannel.

J. Geikie⁴⁸ sees in the alternation of coal and limestone, evidence of prevailing subsidence, while the coal seams indicate frequent recurrence of land surfaces. The cannels and iron-stones show that many wide lakes and lagoons existed. He finds lines and ribs of cannel associated with splint and even ordinary coals, while the cannel itself passes into common coal or black shale or even into black-band ironstone. The varying conditions are due to the mode of accumulation. Cannel was formed under water, for it contains fresh or brackish water fossils. The expanse of fresh water was surrounded by wooded flats; slimy vegetable mud, with, in places, ferruginous matter, was deposited where the streams entered. Along the shores were marsh plants, while farther back were trees and fern undergrowth. The last gave ordinary coal, the marshy plants were converted into splint, while the slime became cannel, oil-shale or even iron-stone.

Stevenson,⁴⁹ as the result of studies in the Upper Coal Measures (Monongahela) of Ohio and West Virginia, came to the conclusion that at the close of the Lower Barren Measures (Conemaugh) the northern part of the Appalachian area basin was a half-filled trough separated from the western coal areas by the Cincinnati fold. He accepted the *in situ* doctrine without reserve. The conditions observed in the Upper Coal Measures prove a succession of gradual subsidences interrupted by intervals of repose, during each of which a lid of coal was formed over all or part of the basin. The subsidence could not have been paroxysmal, for, as the shore line sank,

⁴⁸ J. Geikie, "On the Geological Features of the Coal and Iron-stone-bearing Strata of the West of Scotland," *Journ. Iron and Steel Inst.*, Vol. III., 1872, pp. 13, 14.

⁴⁹ J. J. Stevenson, "The Upper Coal Measures West of the Alleghany Mountains," *Ann. Lyc. Nat. Hist.*, N. Y., Vol. X., 1873, pp. 226-252.

the great marsh, which became the Pittsburg coal bed, crept up the shore—and this perhaps to the very close of the epoch. Thus it is, that though giving origin to many subordinate seams, the great bed diminishes westward. The Pittsburg coal bed began at the east and advanced westwardly. There is evidence in the distribution of sandstones and shales that a delta formation at the east pushed out into the basin, so that conditions favorable to coal-making existed first on the east side of the great basin. His summary is:

(1) The great bituminous trough west from the Alleghanies does not owe its basin-shape primarily to the Appalachian revolution. (2) The coal measures of this basin were not united to those of Indiana and Illinois at any time posterior to the Lower Coal Measures (Allegheny) and probably were always distinct. (3) The Upper Coal Measures (Monongahela) extended as far west as the Muskingum river in Ohio. (4) Throughout the Upper Coal Measures epoch, the general condition was that of subsidence, interrupted by longer or shorter intervals of repose. During subsidence, the Pittsburgh marsh crept up the shore, and in each of the longer intervals of repose it pushed out upon the advancing land, thus giving rise to the successive beds of the Upper Coal Measures. (5) The Pittsburgh marsh had its origin at the east.

Two years later,⁵⁰ after further studies in West Virginia, he offered additional arguments in favor of his suggestions and extended the scope of his hypothesis. The Appalachian basin at the beginning of the Upper Coal Measures was closely landlocked, communicating with the ocean at the southwest by a comparatively narrow outlet. At the east and southeast, rivers brought in their loads of detritus to be spread over the bottom of the basin; on the opposite side, few and sluggish streams flowed from the low Cincinnati fold. During periods of repose, deltas were formed and the marsh advanced on the newly formed land. If the period of repose were long enough to permit the filling of the bay, the marsh would extend across if begun on one side, or to the middle if passing out from all sides. The basin in West Virginia was never so filled with detritus as to permit coal beds to cross it. The Appalachian basin was never

⁵⁰ "On the Alleged Parallelism of Coal Beds," *Proc. Amer. Phil. Soc.*, Vol. XIV., 1875, pp. 283-295.

united with those at the west, anywhere north from Kentucky and he leaves to others to decide if there was at any time a connection farther south.

Still later,⁵¹ after very detailed studies in southwest Pennsylvania, he discussed the question Are coal beds continuous? He describes the Pittsburgh, Waynesburgh, Waynesburgh A and Washington coal beds as practically continuous in the northern portion of the Appalachian basin within Ohio, Pennsylvania and West Virginia—that is to say, that they are almost invariably present wherever their horizon is reached. But that is not true of the intermediate beds, which frequently are wanting in considerable areas; yet they are constant in many great spaces of from 100 to 1,000 square miles: he cannot resist the conviction that these beds are not in isolated patches but that for the most part these apparently separate areas are merely parts of a connected whole. The barren spaces mark localities which did not present conditions favorable to accumulation of coal. Respecting coal beds older than those of the Upper Coal Measures, he is convinced by the evidence of borings, that all, with possible exception of two, merely fringed the border of the basin.

Andrews,⁵² in rendering the final report upon his work in southeastern Ohio, presented the conclusions respecting formation of coal to which he had been led by his many years study of the Ohio measures.

The Lower Carboniferous detrital rocks were deposited in shallow water; the sandstones show ripple marks, striæ and branches of marine plants (the indefinite *Spirophyton*). Some conglomerate appears in the early part of the Coal Measures, but it is confined to the shore side of the basin and disappears eastwardly [toward the center of the basin]. Rocks exhibit rapid variations laterally; sandstones pass into shales; limestones into shales and sandstones. Some marine limestones, formed in shallow water, indicate, as do the coal beds, pauses in the almost continuous subsidence; but the great limestones of the Upper Measures [Monongahela] are to be considered merely as calcareous muds, for they vary as do the other mud rocks.

⁵¹ 2d Geol. Surv. Penn. Rep. KKK, Harrisburg, 1878, pp. 283-295, 301-303.

⁵² E. B. Andrews, Geol. Survey of Ohio, Vol. I., Part I., Columbus, 1873, pp. 345, 347-351, 354, 357, 358.

They were deposited in shallow water, for they are close to coal beds and show the shrinkage cracks due to drying.

Andrews adheres to the doctrine of accumulation *in situ*, asserting that his studies leave no room for any other conclusion. The vegetation grew on marshy plains skirting the ocean or perhaps making low islands near the shore. Slates as coal partings are of great geographical extent, holding the same stratigraphical position throughout, thus implying a temporary overflow of the marsh by ocean waters, with an even distribution of the sediment. Some beds contain evidence of tidal flows, for beachworn sticks, replaced by pyrite, lie in the coal as they were drifted upon the marsh. After complete submergence of the bog, trees growing on the surface were overthrown by turbulent waters; thousands of trunks of *Pecopteris arborescens* are seen in the roof of the Pomeroy coal bed, bent or broken down by the sediment-carrying water; and with them are great trunks of *Sigillaria* and *Lepidodendron*; while, in sandstone, drifted and buried trees from upland areas are not rare. The continuity of coal seams was often interrupted, as should be expected in great areas.

Andrews's studies were confined chiefly to southeastern Ohio and the adjacent portions of West Virginia, where the coal area approaches the central part of the basin, the original western border having been many miles beyond the present western limit of the Coal Measures. The irregularities of deposit are comparatively insignificant and the important members show a remarkable parallelism. He was led by the phenomena of his region to deny the possibility of notable variations in thickness of intervals between coal beds and he refused to accept as correct the great variations reported from the anthracite areas.

There are many evidences of erosion and planation during deposition of sandstones. The great bed on Sunday creek shows erosion from one foot to entire thickness of the bed, the overlying sandstone filling the trench and resting unconformably on the eroded edges of the coal. The eroded surface is smooth, there being no traces of rough work such as one should expect to find, if the coal were still soft and unconsolidated at the time of removal.

Andrews thought that cannel was originally vegetable mud. He emphasizes the abundance of *Stigmara*, saying that they fairly reveled in this ooze. They, with their rootlets, abound throughout; their existence in these beds for hundreds of miles almost necessitates the conclusion that they are *in situ*. If they are roots of *Sigillaria*, those trees must have grown in the wettest portions of the marsh, which, in that case, could not have been lagoons. The *Stigmara* are evenly distributed. If they had been drifted in, he thinks they ought to have gone to muck with the rest.

Newberry,⁵³ in the following year, discussed the origin of the various deposits composing the Coal Measures. The coarse rock underlying the series contains rounded pebbles of quartz, igneous and metamorphic rocks, with rounded and angular sand of the same material as well as cherty pebbles from the Lower Carboniferous. The pebbles for the most part must have come from Archean areas at the east and north; but he finds difficulty in explaining how material from those areas could be distributed in sheets at hundreds of miles from the only possible sources of supply. It is difficult to conceive of rivers as the transporting agency and he is inclined to find the explanation in the drift deposits of the Mississippi valley, ice being the transporting agent. Where the rock is coarse, fragments of the tree trunks, of *Calamites* and of roots are present, all broken, and sometimes heaped in masses covering several rods. Fruits, like *Trigonocarpum*, occur in hollow calamites and the mass is like driftwood, everything broken and battered.

The fireclays sometimes contain stumps of *Sigillaria* and *Lepidodendron* in unbroken connection with *Stigmara* roots. Coal is seldom wanting above fireclay, though at times it has been removed by erosion. Coal beds were formed *in situ*. Fine sediment accumulated in pools and these were invaded by vegetable growth, to be filled up finally by bitumenized remains of generations of plants. Aquatic plants remove alkalies, phosphorus, sulphur and silica from the soils, as is seen in peat bogs, where the underclays are often fireclays. The varying deposits are explained by alternate elevations and depressions of the surface. Limestones were formed in arms of the sea and their presence is proof of unequal subsidence.

⁵³ J. S. Newberry, Geol. Survey of Ohio, Vol. II., part I., Columbus, 1874, pp. 104-115, 118.

Newberry opposed the doctrine that spores of cryptogamous plants are important constituents of coal. Sporangia and spores are common enough in American coals but they are an inconsiderable part of the whole.

Dana,⁵⁴ reasoning from chemical analyses, objected to Dawson's suggestion that coal was derived largely from bark or material of that nature. Though nearer coal in composition than is true wood, bark resists alteration longer and is less easily converted into coal. The occurrence of stumps and stems outside of the coal beds, "while proof that the interior wood of the plants was loose in texture and very easily decayed, is no evidence that those trees contributed only their cortical portion to the beds of vegetable debris. Moreover, the cortical part of *Lepidodendrids* (under which group the *Sigillarids* are included by the best authorities) and of Ferns also, is made of the bases of the fallen leaves, and is not like ordinary bark in constitution; and *Equisetæ* have nothing that even looks like bark. This cortical part was the firmest part of the wood; and for this reason it could continue to stand after the interior had decayed away—an event hardly possible in the case of a bark-covered conifer, however decomposable the wood might be. Further, trunks of conifers are often found in the later geological formations, changed *throughout* the interior completely to Brown coal or lignite." He appears to be convinced that the whole plant material contributed to formation of the coal, which he regards as the product of marsh accumulation.

Dawson⁵⁵ returned to the discussion in view of Huxley's assertion that spores are an important constituent of the coal-forming mass. Referring to his study of more than eighty coal beds in Nova Scotia and Cape Breton, he asserts that the trunks of *Sigillaria* and similar trees constitute the great part of the densest portion of the coal and that cortical tissues, rather than wood, predominate. Spores and spore cases, though often present abundantly, constitute only an infinitesimal part of the great coal beds. Sporangites or bodies resembling them are present in most coals, but they are acci-

⁵⁴ J. D. Dana, "Manual of Geology," 2d ed., New York, 1874, pp. 361, 362, 366.

⁵⁵ J. W. Dawson, *Amer. Journ. Sci.*, 1874. Supplement to 2d ed. of "Acadian Geology," 1878, pp. 65.

dental rather than essential constituents, more likely to be found in cannel and shales, deposited in ponds near lycopod forests, than in the swampy or peaty deposits, whence the coal beds proceed. While giving credit to Huxley and his predecessors for calling attention to the importance of spores in coal, he is compelled to maintain that they have generalized on insufficient basis, that sporangitic beds are exceptional among coals and that cortical and woody matters are most abundant. The purest layers of coal are composed of flattened trunks; other coals are made up of finely comminuted particles, mostly epidermal tissues—not only from fruits and spore cases but also from leaves and stems.

Mietzsch⁵⁶ attempted to answer the question, how did the vegetable material accumulate in great beds? Was it brought down by rivers from forest covered areas or did the plants grow where the coal is now found? The mode of occurrence can be explained measurably by either supposition; at times one process may act alone, at time it may be permissible to regard both as contributing.

He describes the heaping up of driftwood along streams as well as on coasts, whither it has been carried by currents; and he thinks that in this way may have originated some tertiary deposits of lignite, composed almost wholly of stems stripped of their bark. But many deposits of lignite and brown coal contain stems with bark, twigs, leaves and fruit preserved. The Suterbrander lignite of Iceland was formerly supposed to be driftwood, because of the present conditions in that land; but Heer discovered well-preserved buds, leaves and twigs of the plants, represented by the stems, which still retain their bark. The same criterion must be applied to the black coals. Many deposits of these and the greater number of brown coals have numerous tokens, rendering improbable, in part impossible, the supposition that they were made of transported plant masses. It is difficult to understand the regularity and vast extent of coal beds on the theory of transport, for driftwood accumulations are irregular and of small superficial extent.

The composition of coal tells against the theory of transport, for in most beds the ash is very small—surprisingly small, for in the process of coalification no part of the mineral content of the plants

⁵⁶ H. Mietzsch, "Geologie der Kohlenlager." Leipzig, 1875. pp. 244-257.

disappears, aside from soluble alkaline compounds. Some have found proof of transport in the composition of ash from stone coal, since it is quite similar to clay shale. But Mietzsch points out that living *Lycopodiaceæ* contain from 22 to 26 per cent. of clayey earth in the ash and asks why one should suppose that the older types were different. But if the coal contain an abnormal proportion of ash, there is reason to recognize influx of fine mud.

The fineness of the materials, clay and sand, in contact with the coal, proves a long period of quiet; and the same may be said of the plant deposits themselves. Such a period can hardly be accepted for rivers or for currents along coasts. The conditions of the underclay; the resemblance of the clay in many cases, as Steffens showed, to vegetable mould; the interlacing of *Stigmaria* roots like wicker work; and the occurrence of erect trunks are all opposed to the doctrine of transport. In most cases the conditions can be explained only by the doctrine that coal beds owe their origin to plants which grew where their remains are now found. He accepts the peat bog theory as advanced by v. Beroldingen and presents many facts as additional evidence in its support. The advance of bogs into lakes is proved by the discovery of pile constructions in Swiss peat bogs; along the seashore, algae form dense floating felts on which bog plants grow and the mass sinks to the bottom. Zealand was once cut by bays much longer than now and part of the former sea-area is filled with peat. He strengthens his argument by many references to phenomena observed in the great swamps of Europe and North America.

In order to explain the origin of coal-bearing strata, holding a number of coal beds, one must distinguish between those formed along a coast and those formed along rivers or in the interior of an island or continent. Those of the first type are explained by the subsidence of coasts bordering on the North Sea. The preliminary work for drainage of the Zuyder Zee, as well as similar work elsewhere, has proved the existence of peat bogs in extended areas of shallow sea; anchor flukes have brought up peat from depths of 200 meters on the English coast. Such bogs become covered by river sediments and in case of long-continued slow sinking, the shallow sea area is filled, so that a number of bogs may be formed suc-

cessively. Among other illustrations, he refers to the discovery at Rotterdam of two bogs, 5 and 6 meters thick, separated by 4 meters of clay; to the presence of erect trees which, despite the long period which has passed since they sank below the water surface, are still standing on the sea bottom, partly surrounded by sediments; such trees on the coast of the islands of Sylt and Romo are of types which disappeared from that region many hundreds of years ago.

Changes in grade of rivers, caused by damming or by crustal movements, would lead to covering of bogs with sand or mud and to the accumulation of rock masses. He finds confirmation of this view in Livingstone's statements respecting the floods of African rivers and in the observations of others elsewhere.

Lesley⁵⁷ in prefaces to reports by geologists of the Pennsylvania survey, made frequent references to hypotheses respecting formation of coal beds. Ordinarily, he preferred to present the matter, as it were judiciously, giving the difficulties in the way of accepting the hypotheses and leaving the decision to the reader. But in two of the prefaces he offers some important suggestions.

W. G. Platt described a little basin, barely a mile and a half across, in which three sections of Coal bed D were obtained. In all of them, the bottom bench is 2 feet 7 inches thick and composed of brilliant coal; but the upper part is a dull cannel or cannel shale, measuring 1 foot 3 inches, 8 feet 3 inches and 1 foot 2 inches, while between the last two the dip is about 8 degrees compared with about one degree elsewhere. A noteworthy feature is that while the ash in the cannel is from 21 to 25 per cent. and that in the pure coal below is only 1.6 per cent., yet the ratio of volatile matter to fixed carbon is practically the same throughout.

Lesley felt convinced that the petty basins, in which cannel was deposited, were waterways or pools and that more of them existed at once in certain horizons than in others. They were not due to erosion for the underlying coal bed is not cut out, it is merely depressed. There is no evidence of currents, for the mud is fine, the lamination perfect and the roof soft. The pools were almost stagnant. How could a depression come about to give, as here, a dip

⁵⁷ J. P. Lesley, Second Geol. Survey of Pennsylvania, Indiana County, 1878, pp. xiv-xviii; Lawrence County, pp. xix-xx.

of 5 to 10 degrees to an almost dead level bituminous coal bed? There is no room for suggestion of crustal movement as the area is too small; equally the cavern theory is excluded for no limestone underlies the horizon except at vast depth. He can see no explanation for most of the localities except in the subsidence of a floating bog, such as Lesquereux has described. On this the fine muds accumulated and the pool was filled.

He was led in this connection to consider the sequence of coal beds. If the Carboniferous plain consisted of a low area with shallow ponds, the coal forming vegetation would conform to the dimpled surface and there would be but one coal bed, intersected by river channels. This plain, if continuous, would be not less than 1,000 miles long by 300 miles wide [this refers to the Appalachian basin]. It is very difficult to account for the submergence of this continental plain to a depth of 50 feet below sealevel in order to give opportunity for formation of a second bed. Yet this "slow depression theory" may not be rejected easily, for without it, one cannot conceive how 20,000 to 40,000 feet of palaeozoic sediments could have been deposited; the more so, since many of the strata give every evidence of deposition in very shallow water. As a partial alternative, he suggests that the relative sea level may have been changed by the filling of basins. The effect of deposits by great rivers and that of glaciation are discussed but no conclusion is reached.

In the preface to the Lawrence report, he attempts to explain the origin of underclays. A peat bog and even a lake invaded by sphagnum growth must have some water circulation due to percolation from the surrounding land and to evaporation from its own surface—but the movement would be very feeble and it could transfer only the finest mud, though in course of time the result would be important. Dry grounds are largely fine gravel with rounded quartz and feldspar grains; the feldspar is soluble, it follows the indraught and settles beneath the evaporating surface with its floating peat. If the peat area be surrounded by clayey land, the percolation would be at a minimum; the water supply would be from the surface and less muddy, so that the underclay would be less in quantity. It would appear, then, that when the margin was a tight clay, deposits

of calcareous type show that limestone must have been exposed within the drainage area.

The thickest underclays should belong to beds next or near above the great sandrocks and it is a fact that our great clay beds are near the base of the Lower Productive Coal Measures [Allegheny] and that the few important clay deposits high in the series have coarse grained sandrocks not far below them. A logical consequence of such conditions is that sandrocks geologically close to such great underclays should be purer, more open sands and gravels than others which had not been robbed of so large quantity of interstitial clay. If the surrounding land contained iron in its gravel, there should be ball ore in the fireclay—as is seen in the New England ponds surrounded by drift.

Davis⁵⁸ described a cannel deposit in Yorkshire, somewhat resembling that discussed by Lesley. The bed is thickest in the center and thins away in each direction, meantime becoming less pure and passing into bituminous shale at the circumference. The condition is due to in-floating of plant remains, which sank to the bottom of the pond. The marked interlamination of shales and their marked increase toward the border resulted from more rapid subsidence of the muds. In some places the pond was filled up; there the underclay has abundance of *Stigmara* and the plants growing in such places were converted into ordinary coal. Afterwards the whole mass was submerged and covered with black mud. The cannel is fine, close-grained, homogeneous, with conchoidal fracture, without planes of deposition and everywhere yields beautiful specimens of fishes.

Reinsch⁵⁹ undertook the microscopic study of coal. He prepared a great number of sections, subjected them to close examination and published his results in an elaborate volume with 95 plates. These exhibited the structure of the coal as well as numerous forms which seemed to be organized. Reinsch maintained that the coal

⁵⁸ J. W. Davis, "On the Fish Remains found in the Cannel Coal of the Middle Coal Measures of the West Riding of Yorkshire," *Q. J. G. S.*, Vol. XXXVI., 1880, p. 56.

⁵⁹ P. F. Reinsch, "Neue Untersuchungen uber die Mikrostruktur der Steinkohle des Carbon, der Dyas und Trias," Leipzig, 1881.

substance originated, mainly, from marine plants of such peculiar form that they cannot be assigned to any group of known types. He created a new group for their reception, *Protophytæ*, of which he made seven divisions. Remains of land plants are of very rare occurrence. This hypothesis differs from that of Mohr in that the plants are microscopic.

Petzholdt⁶⁰ at once made a fierce critique of Reinsch himself, his methods and his results. Of the seven divisions of *Protophytæ* two are decomposition products, three are certainly inorganic, one consists of fragments of land plants and one is based on minute fragments of coal. The decomposition products, mistaken for organic bodies, are termed bitumen by Petzholdt, who thinks them the same with those discovered fifty years before by Hutton in his study of the Newcastle coals.

Fischer and Rust,⁶¹ following Reinsch's method, found not only yellow and reddish resin-like bodies in black coal, such as make up the great part of the Scotch boghead, but also small grains, showing wood structure, in anthracite. In the black coal, they observed spindle-shaped or serpent-shaped bodies, whose relations they could not determine. The English cannel from Lancashire is very rich in little resinous cylinders and, as far as richness in resinous matter is concerned, is intermediate between the Bogheads and the ordinary coals. These studies have an important bearing on investigations which have attracted much attention in more recent years.

Green⁶² says that it is not easy to see how light material, such as dead wood, could be spread out evenly over tracts of hundreds of square miles, so evenly that the deposit shows comparatively little variation in thickness; and it is equally difficult to understand how, in case the coal be composed of drifted materials, it could be so pure as we often find it. The water bringing the vegetable matter

⁶⁰ A. Petzholdt, "Beitrag zur Kenntniss der Steinkohlenbildung," Leipzig, 1882, pp. 23 et seq.

⁶¹ H. Fischer and D. Rust, "Ueber d. mikroskopische Verhalten verschiedener Kohlenwasserstoffe, Harze und Kohlen," *Groth Zeitschrift f. Kryst.*, Vol. VII., pp. 209-243. This has not been seen by the writer. Cited by Petzholdt and v. Gümbel.

⁶² A. H. Green, "Geology," Part I., Physical Geology, London, 1882, pp. 257-262.

would certainly carry also mineral matter. The coal and its ash may, both of them, be of vegetable origin. Logan's discovery of the underclay or Seatstone under nearly every coal bed was the first great step in the right direction toward solving the problem. Binney's study of an erect stump discovered by Hawkshaw near Manchester was the next, for there a *Sigillaria* with *Stigmaria* roots was rooted in a seat clay, while the stem was surrounded by rock. Many similar cases were discovered. The underclay was the old soil supporting plants which produced a layer of nearly pure vegetable matter. When the surface was lowered beneath the water, sand and clay were laid on top and the band of dead plants was converted by pressure and chemical change into a seam of coal.

When sinking ceased, the shallow water was filled up and a swampy plain was made. Vegetation spread out from the land and a second coal bed began to accumulate. This process repeated many times over gave a succession of sandstone and shale with coal beds at intervals. The great swampy expanses in the delta of the Ganges and Brahmapootra must bear close resemblance to the marshy flats in which the coal was formed. The nearest approach, however, is in the accumulations on the coast of Patagonia, described by Lady Brassey in "A Voyage in the Sunbeam"; "To penetrate far inland was not easy owing to the denseness of the vegetation. Large trees had fallen and, rotting where they lay, had become the birthplace of thousands of other trees, shrubs, plants, mosses and lichens. In fact in some places, we might almost be said to be walking on tops of the trees, and first one and then another of the party found his feet slipping through into unknown depths."

There are, however, deposits of subaqueous coal, derived from driftwood carried down and buried amid mechanical deposits, but they are irregular and are apt to be impure. It is probable that the patches of cannel coal mark sites of pools or lakes in which vegetable matter lay until it was macerated into a pulp. This passes gradually by increase of earthy admixture into well-stratified carbonaceous shale.

Green had already presented the same suggestions, though briefly, in his work on the Yorkshire coal-field published in 1878.

Grand' Eury,⁸⁸ in the first section of his notable memoir, gives the grounds on which his theory of transport is based.

When one makes minute examination of coal, he discovers that the plants have been broken up and the parts scattered; fruits and leaves are apart from the stems; the layers of the bark are separated and dispersed; the interior parts of the stems have disappeared and the flattened cortex alone remains. The woody portions of the stems have been dispersed as fusain [mineral charcoal]. Stems are split and torn, *Cordaites* leaves are imperfect, everything, bark or leaf, is broken up. He thinks that a great part of the tissues was transformed into a kind of vegetable pulp, which makes up most of certain coal beds. That this was not wholly fluid or homogeneous is evident, for one may distinguish some traces of organization with the microscope or even with a magnifying glass.

The disintegration of the plant organs occurred after death and its character puts aside all suggestion of violent action. All the evidence contradicts the supposition that the forests were ravaged by inundations; everything points to quiet, peaceable flow of water. Most of the material was decomposed in place and carried away piecemeal. The vegetable matter was not deposited in deltas within either the north or the center of France.

The preservation of stems reduced to their bark is not surprising, for there was little wood in trees of the Carboniferous; but the mineral charcoal is not so easily accounted for. It seems to be fossilized buried wood, dried in the air and not changed into coal. It did not originate through maceration, though after formation it may have been subjected to moisture, as is indicated by lack of sharpness in outline.

The vegetable disaggregation was rapid, mostly in air, and was completed in swamps before removal. The conversion into detritus and the quasi-dissolution were sometimes pushed very far at the base of damp forests and at the bottom of swamps. The Carboniferous forests were marshy and aquatic. The plants grew quickly, reached maturity and soon died. Growth had to be energetic in order to carbonize the bark so as to make the contraction

⁸⁸ G. Grand' Eury, "Memoire sur la formation de la houille," *Ann. des Mines*, Ser. 8, T. i., Paris, 1882, pp. 101-122.

small in coalification. That the air was damp and warm is proved by the aerial roots of *Psaronius* and *Calamodendron*; and the heat of the climate appears from the dense resinous bark, which often dominated the wood. Strong light, great heat, excessive humidity, great marshes in which plants grew quickly and died, explain conditions not easily explained by conditions of the present time. The residues falling into the marshy bottom of the forest, underwent aqueous rotting; they were then transported to the areas of deposit, which preserved them from complete destruction.

Grand' Eury published much relating to this subject and in 1900⁶⁴ he summarized all the results of his long studies in a memoir presented to the geological congress.

He describes fossil forests *in situ*, which show that the Carboniferous plants, though arborescent, were forms of marsh-habit like those of the Dismal Swamp, the foot and adventive roots in the water, but the stocks and rhizomas creeping on the bottom. The forests were very local. Growing in stagnant water and fixed by few roots to the ground, they were destroyed by slight causes and the roots alone remained. This would give a "soil of vegetation" as described by Dawson—a feature as familiar at Saint-Etienne as in Canada.

Coal is stratified, evidently deposited under water. There is no evidence that roots ever traversed the parallel laminæ of which it is composed. The stocks and roots, descending in the roof, spread out on the coal but never penetrated it. This condition is constant and is due to the circumstance that slowly deposited vegetable matter, undergoing fermentation, is opposed to the introduction of roots, which, being unable to live in it, instinctively refuse to pierce it. Similarly there is no relation between stocks and overlying coal. Their roots are often enclosed in coarse twisted coal composed of overturned stems, with leaves, branches, which, however, is continuous with overlying laminated coal. The elements are the same in both and they are identical with those in the adjacent shales, so that transportation from a distance is impossible. There is then in some coal beds evidence of formation in place or almost in place.

⁶⁴ C. Grand' Eury, "Du bassin de la Loire," *Compt. Rendus VIII^{me} Congres Geol. Intern.*, Paris, 1901, pp. 521-538.

But most of the material forming the beds was transported; yet all coals resemble that found almost in place and the parts, certainly transported, are identical with similar parts of the rooted stems. The materials were derived from marshy forests on borders of the basin, which doubtless succeeded those temporarily installed in the basin of the deposit which afterwards became a lake. At the foot of this forest was elaborated, as in peat bogs, the humus or fundamental material of the coal. The basin of deposit was much like the bottom of a morass, for the mud of coal beds often resembles the clay underlying peat bogs. The debris of plants falling into water on the borders of the marsh became stratified in its depths. Grand' Eury was convinced that by this hypothesis he had reconciled the opposing theories, for he has shown that certain coal beds were formed by concurrence of both processes, as in the sub-aquatic parts of some swamps.

The permanent swamps, where primitive peat was elaborated, were not exposed to deposit of mineral sediments, they remained uncovered and disappeared; so that very little of the coal formed in place remains. The researches of Renault and C. E. Bertrand on cannel and the fundamental matter of coal show that coal was not always deposited on lake bottoms under moving waters, but that it may have been formed in stagnant or quiet waters of swamps.

The coal was deposited slowly, not continuously and there may have been long periods of arrested growth. The concentration of fossil forests and soils of vegetation in and near coal beds proves for the thick beds a very long period. Additional evidence in this direction is found in the advanced decomposition of the rocks forming the roof, their new chemical combinations, their impregnation with carbon, showing that they had been long in contact with the swamp before being transported and deposited on the coal bed.

The basin of the Loire was subjected to orogenic movements. The fossil forests have irregular distribution both vertically and horizontally; great sterile deposits break up the continuity. The basin was deepening throughout the period of formation, but each important coal bed corresponds to an interval of stability. That the mineral materials were brought in by streams is shown by their

distribution. The granitic rocks of the northern portion thin toward the south and their rooted stems lean toward the south and south-east; but the micaceous rocks of the southern portion thin toward the north and the rooted stems lean in the same direction, sometimes strongly. These mineral deposits interlock as wedges. But the coal beds pass from one type of rock to the other, preserving well their distance and parallelism. Grand' Eury finds no evidence to support the delta-theory of accumulation in deep basins; every feature leads to the belief that the mass of rocks could accumulate only by means of a subsidence, equal and progressive from the clay bottom.

In a still later paper,⁶⁶ Grand' Eury shows that coals of all kinds are practically alike in origin.

Coal beds are deposits of allochthonous peats formed by an exuberant vegetation, loving water, whose detritus was carried from shores to interior of immense marshy lagoons, where barks, cuticles and the rest were stratified with ulmic substances under the water. Stipites or dry coals of the Secondary in France are clearly the same in origin with the coals. Mineral charcoal is so abundant in one of the Upper Cretaceous coals as to give a finely-stratified structure to the bed. The brown coals of the Tertiary resemble coal completely in mode of occurrence; they are composed of marsh plants, leaves of dry land plants being in small proportion. Lignite is wood-like in appearance though formed of red humus from plants; they show much variation, but the mass of the material is derived from marsh forms. The peats of lowland areas or marshy plains are allochthonous—they resemble almost all deposits of mineral coal.

Gruner⁶⁶ notes the ancient forest in the quarry of Treuil, which had been described by Alex. Brongniart many years before. At 100 meters lower and almost directly under the quarry, Gruner found in the Treuil mine twelve great trunks in a space of less than 10 meters square; their roots spread out over the coal but did not penetrate into it.

He cannot accept the doctrine that coal consists of transported material. The continuity and uniformity of coal beds make a serious

⁶⁶ C. Grand' Eury, "Sur la formation des couches de houille de stipite, de brownkohle et de lignite," Autun, 1902, pp. 123-132.

⁶⁶ L. Gruner, "Bassin houiller de la Loire," Paris, 1882, pp. 160-170.

objection. In the little basins of Saint-Etienne, beds can be followed 5 to 10 kilometers in one direction and 2 to 4 in another with little change. He thinks that a current capable of uprooting trees would tear away the soil and pebbles also, so as to give a mingling of trees and detrital matter.

As large streams carry much mineral material there should be an alternation of vegetable elements and mud—and this is found in coal beds where shale appears in thin layers between benches of coal. These shales or the nerfs of fine sandstone could be produced only by water-currents, by inundations of brief duration covering the debris on the surface or invading shallow basins in which leaves, etc., were deposited slowly. The two modes of accumulation went on simultaneously in the coal period as they do now in peat bogs. He does not assert that coal was the peat of palaeozoic times; the flora and the climate were different; but the mode of formation was the same. The plants of the coal epoch grew where their remains are found. He cannot accept Grand' Eury's theory, which opposes the doctrine of *in situ* accumulation because stumps and trees are wanting in the coal beds themselves. Grand' Eury maintains that the vegetable matter was transferred from the place of growth to the basin where the coal is found, but the distance was small.

Gruner maintains that the current would have brought more than leaves and stems and that it would have distributed its load unequally; he thinks it preferable to conceive of a marshland extensive enough to admit of a thick cover of vegetable débris over an area of several thousands of square kilometers—as one finds in the Nord basin. Grand' Eury emphasizes the absence of stumps and roots passing from coal beds to the mur. But at Saint-Etienne itself, Lyell and Gruner saw rootlets passing from the coal into the underclay and Gruner saw the same condition in the Batardes coal bed, where *Stigmaria* abounds in the mur. The absence of stumps in the coal is to be expected, because the soft tissues would be crushed quickly under pressure and all traces would be effaced; moreover, in the nature of the case, stumps would be only a small portion of the mass. A negative result of study does not prove that the plants

did not grow *sur place*. Since the rapid current, which piled sand around the forests of Treuil, did not uproot the trees, one finds difficulty in understanding how the waters so slightly agitated as to be able to draw off only leaves and twigs did not leave in place the stumps whose roots are seen to-day in the underclays.

The preservation of the underclay proves that the stumps were not torn out before deposit of the plant debris forming the coal bed. The clay shows no signs of erosive action such as are seen so often in the roof. The deposit of the clay is itself a proof that then had begun the long period of tranquillity, which continued during formation of the coal. He is convinced that it must be admitted as almost proved that the coal beds have come from a vigorous local vegetation, whose debris accumulated at the bottom of shallow stagnant water and probably, quite as often, on a damp but not flooded surface.

The intervening rocks are, in character, wholly similar to partings in the coal beds, but they were formed not by petty inundations but by strong currents of prolonged duration. The existence of these is proved by erosions as well as by the sands which covered the coal forests. The surface subsided at intervals, as shown by phenomena connected with the faults in the Loire basin. But the flora was not destroyed, for one finds forests or isolated trees in place, in sandstones at all horizons, their bark preserved as coal. The sands are evidence that the agitated water prevented quiet deposition of vegetable debris. That was destroyed or scattered afar.

Meanwhile, the sunken surface was leveled up and the depression was filled. A second marsh was formed above the first, now buried under a thick bed of sand or mud. If the deposit of sand, etc., did not exceed 30 meters, the conditions under which the new bed was formed might not differ from those of the earlier bed. But when the sterile interval attains great thickness, 100 to 800 meters, the period of depression was very long and before its close the flora had undergone modification. Thus it is that one finds successive appearance of varied types, so that classification of the Coal Measures by their flora becomes possible. Subsidence of the type here conceived has been observed in rocks of all epochs. Lament and

Degousie, in sinking artesian wells at Venice, found beds of lignite and carbonaceous clays at 40, 60, 100 and 120 meters from the surface.

Von Gümbel,⁶⁷ perplexed by the contradictory results presented in memoirs, undertook a series of systematic studies, covering all phases of the subject. His study did not concern itself with chemical or technical matters and had little reference to botanical relations. At the outset, it deals only with questions relating to the constitution of coals; it begins with examination of peat-like substances and advances, step by step, to anthracite and graphite; it ends with a discussion of the mode in which coal beds accumulated. In breadth of scope, this study excelled that by any predecessor; in compactness and precision of statement the memoir has rarely been excelled. Much of the earlier portions bear directly on questions respecting the transformation of vegetable matter into coal, a subject to be considered in a later part of this work; but some of his observations are so closely connected with the final part of his discussion that they cannot be neglected.

The method of investigation by means of thin sections did not commend itself to v. Gümbel, who preferred the method proposed by Franz Schultze. The broken coal was treated first with potassium chlorate and strong nitric acid, and afterward with ammonia, in order to separate the particles and to make the transparent portions more readily available. Absolute alcohol completed the preparation by removing coloring matters. He gives specific directions as to the use of the reagents and warns against the possibilities of error in the study.

This investigation led him to recognize that the whole series from peat to anthracite is continuous and of similar origin. All of the members are made up of combustible materials. "Stone coal consists, apart from the earthy admixtures, of parts of plants, which, changed into a coaly substance, have taken up into their empty spaces, as well as into the intervals between the plant débris, a humin-like or ulmin-like substance (carbohummin) which was origi-

⁶⁷ C. W. v. Gumbel, "Beitrage zur Kenntniss der Texturverhältnisse der Mineralkohlen," *Sitzungs. Berichten der k. bayer. Akad. d. Wissenschaften. Math.-Phys. Klasse*, 1883, pp. 113 et seq. The citations are from pp. 190-212.

nally soluble, but became insoluble, so that the whole is amorphous and apparently structureless." The taking up of this material is the *Inkohlungsprozess*.

Adjacent rocks, containing plant remains, may have contributed to this coalification by means of circulating waters. It is self-evident that this soluble material might be deposited by itself apart from any remains of plants, not merely as layers of a coal bed but also in cracks and fissures; but such layers of structureless coal could have contributed in only subordinate manner to the formation of coal beds.

The several types of coal, *Glanz-*, *Matt-*, *Faser-*, *Cannelkohle* and the rest cannot have originated under similar conditions. In considering these he takes the most complicated condition—where several varieties occur in the same bed. Three modes of explanation are suggested by the investigations: (1) Original differences in kinds and parts of plants; (2) differing conditions, chemical and mechanical, in which the plants came to contribute toward making the coal; (3) heterogeneous external conditions under which the transformation was completed.

Difference in material in the several types of coal appeared constantly during the study; bark, and woody parts along with leaves in *Glanzkohle*; abundance of leaf organs, especially of the epidermis layers and less abundance of hard parts in *Mattkohle*; constant recurrence of little balls, membranes, the spores of authors, in astonishing abundance with algae-like clumps in *cannel-like* layers; all proving a certain dependence of constitution on the character of the plant remains. It is clear that the condition under which the plant material was accumulated was of great importance. This is evident from the great amount of *Faserkohle* [*fusain*, mineral charcoal]. If this material result from decay in free air, as would occur in the occasional drying of the surface in peat bogs, one must concede that this process was of vast extent during the coal-making time. It is unnecessary to suppose that the great supply was swept in; it could have been produced as readily on the bog surface. Similarly the dismembered parts of plants, clods or flocks, and the rest belong to a stadium anterior to formation of the coal. The pres-

ence of plant remains in soil, in every peat bog, justifies us in tracing back in some degree, certain relations of coal formation to similar origin. Accumulation of cannel-like coaly substances cannot be explained otherwise. The tertiary gas coal of Falkenau, pyropissite and Lebertorf all consist of a similar wholly broken up mass of plant parts. External relations had much to do with the conditions. If inflowing water bring much mineral matter into a bog, the borders are impure while the main portion is pure. So a coal may be impure on the borders and pure in deeper portions of the basin. Even the character of the overlying rock may be important.

Passing from the composition of the coals, he considers the mode of accumulation; first of all, rejecting absolutely as without foundation, the doctrine that coal could have been formed in the open sea and from seaweeds.

Coal beds consist of alternating, mostly very thin layers, like beds of sedimentary matter; this, with the fact that they are associated in series with undoubted sediments, seems to afford proof for the opinion that coal beds originate as do other sedimentary strata, in contradiction of the so-called peat theory, which accepts the idea of an origin in place after the manner of peat bogs. If one confine his attention solely to this layer-like accumulation and make no further inquiry, the conditions appear so completely explained by the former doctrine that facts favoring the latter have no value. V. Gümbel thinks that the presence of upright stems is of comparatively little importance as a proof of autochthonous origin, since their presence is exceptional and it can be explained in several ways—by drifting, by advance of waters into swamp forests or by plant growths floating on the water.

A careful examination of the query as to whether or not the lamination of coal can be explained by anything except deposit of suspended matter, leads to surprising results, when extended to the newer coal accumulations. The Quaternary brown coal offers an instructive illustration of the mode in which the lamination originated. These have absolutely the same structure as that of stone coal beds. It is known positively that they owe their origin to peat-like swamps and that the clayey, sandy partings, which accompany

them, proceeded from occasional overflows. Coming down a step farther to the coal making of our own time and ignoring for the present the various local modifications of peat, one can recognize two distinct modifications; Autochthonous, that forming or originating in place, and Allochthonous, the sedimentary, due to deposit of plant detritus in pent up waters. The latter shows, of course, evidence of sedimentary origin, is more or less dense and homogeneous, contains much earthy matter and the plant remains are notably advanced in change. Often it shows lamination only on drying.

All kinds of peat have the lamination. In Moortorf there are often alternating layers, differing in color, density and composition; in Specktorf the structure is especially distinct. Peat then is not an unstratified mass and one cannot say that the lamination of coal places it out of comparison with peat. Close investigation shows so many similarities between the peat layers and those of some coals, that this kind of structure favors rather than opposes comparison of coal-making with peat-making. This lamination appears in the autochthonous peat, in the diluvial brown coal originating in peat and in the whole range of the brown coal formation. But one must remember that the coals were not all formed on the same model; that comparison with peat is only tentative, as modern peat is made from moss and swamp grasses, while in the coal time the deposits came from a wholly different moor and swamp vegetation.

The stone coal formation for the most part is to be regarded as an inland formation, originating in widespread leveling and subsiding of the land, in many cases on swampy lowland along the sea-coast, over which floods distributed materials, such as shale and sandstone. On the extensive but not high land of the Carboniferous time, waters were penned in great areas and became converted into morasses, where a luxuriant vegetation flourished. It is very probable that in occasional drying of the swamp followed by renewal of the flooding, one may find explanation of the alternating bright and dull coal. This does not exclude influx of broken and shattered plant stuff from the higher surrounding region; that might even have predominated in some localities and have been the basis for cannel and boghead. Even from the swamp vegetation itself, decay-

ing material might float away to deep water within the swamp, so as to be heaped into peculiar massive layers like cannel. Flooding of the plain and deposit of mineral matter checked formation of coal; but the swamp would be re-established and a second formation be made; or possibly for a long period only rock material might be deposited.

How far variation in the water niveau may affect the question is considered only so far by v. Gümbel as to let him warn against the conception that basins, now filled by a thick series of coal bearing deposits, were filled with water in like manner at the beginning. These bowls were filled very gradually; they must be thought of as filled temporarily by a relatively shallow pond of water, which little by little reached a higher level.

At times, marine remains occur in strata between the coal beds, a condition which seems opposed to the explanation offered. But this occurrence is due to the fact that the low swamp land was spread out near the sea and was exposed to invasions, so that remains of marine animals might be enclosed in materials originating on the land. Marine or brackish water forms might be enclosed in the coal deposit itself, if it were formed alongside an arm of the sea.

In general, coal beds are an autochthonous product of dead, broken and disintegrated plant fragments with only local and petty contribution of transported material of the same character.

Wethered⁶⁸ called attention to the fact that coal seams are not single beds, but are separated by partings into benches which may differ in quality as well as structure. Sometimes *Stigmaria* are present in the partings.

The Cannock Chase or Shallow seam, near Edinburgh, has in its upper bench, 1 foot 10 inches thick, the brownish layers composed of macrospores and microspores, while the bright layers, containing some woody tissue, are composed mostly of a structureless material which he terms "hydrocarbon" in preference to "bitumen." Whence this comes he does not know, but wood tissue may contribute to it. The middle division of the bed is very different, consisting almost wholly of "hydrocarbon" with very few spores.

⁶⁸ E. Wethered, "On the Structure and Formation of Coal," *Q. J. G. S.*, Vol. XI., 1884, *Proceed.*, pp. 59, 60.

It is possible that spores may have been there and that they may have been decomposed, but spores are much more resistant than is woody material. The main division has a great accumulation of spores but also a fair proportion of the "hydrocarbon." He concludes that some coals are made up practically of spores, others are not; the differences in benches of a coal bed are of this character. Harker, reasoning from the ornamentation of the spores, suggested that they may have come from a plant related somewhat to *Isoetus*.

In the discussion of this paper, Carruthers took exception to conclusions based on markings seen on spores. He knew of no reason for referring those spores to *Isoetus* or any other form of submerged vegetation. Spores in coal were discovered first by Morris; they are associated with *Sigillaria* and *Lepidodendron*; the coal was the soil for the vegetation, penetrated by *Stigmaria* roots of the plants. A *Sigillaria* stem, at the Leeds museum, filled with white sand, penetrated far into the coal in which it grew. Coal seams are remains of forests which grew on swampy ground. The macrospores were not composed originally of brown substance, they are merely filled with it.

E. T. Newton stated that some coals are certainly made up of macrospores and microspores. Dull coal contains spotted tissue; intermediate coal contains both forms of spores; bright coal is a brown substance, usually structureless, but in one case, known to him, it consists wholly of spores.

Dawkins had never found sporangia in coal though both macrospores and microspores are abundant. Coal consists of carbon and resin, the latter giving the property of blazing, which Huxley would attribute chiefly to the spores. With this conclusion, Dawkins agrees only in part. The carbon comes from decomposition of woody portions, but the resin from cell concretions in the living plant. Carboniferous forests grew on level alluvial tracts but little above the water level.

Dawkins,⁹⁹ discussing the geographical conditions in Great Britain during Carboniferous time described the mode in which the coal beds accumulated.

⁹⁹W. B. Dawkins, "On the Geography of Britain in the Carboniferous Period," *Trans. Manchester Geol. Soc.*, Vol XIX., 1887, pp. 45-47.

Oscillations of level still continued as the north, but the land constantly encroached on the shallowing sea, the mud encroaching on the Carboniferous limestone and the sandbanks following the mud closely. Meanwhile "the terrestrial vegetation was spreading from the old Lower Carboniferous land areas over the new Upper Carboniferous marsh lands, from the mountains of Wales and from the other Lower Carboniferous islands, now uplands. These forests contributed in their decay, through many generations, the accumulation which now, compacted by pressure and subjected to earth heat, is familiar to us as a coal seam. Each coal seam represents a land surface, just as the sandbanks and mudbanks (sandstones and shales) above it point to submergence. The fact too that the coal seams in a given section are parallel to each other or nearly so, implies that the forests grew on horizontal tracts of land, just as the associated sandbanks and mudbanks, with marine or freshwater shells, prove that these horizontal tracts were near the sea level or within reach of the waters of a mighty river. We may learn also from the study of the isolated coal fields that this great horizontal tract of forest clad alluvia occupied nearly the whole area of the British isles in the Upper Carboniferous age, from the Scotch Highlands southward, the dead flat being broken only by the higher lands, the old islands of the Lower Carboniferous sea, which I have already described. It was indeed the delta of a mighty river, analogous in every particular to that of the Mississippi—a delta in which from time to time the forest growths became depressed beneath the water until the whole thickness (7,200 feet in Lancashire) was accumulated of coal seams and associated sandstones and shales. After each depression the forest spread again over the bare expanse of sand and mud piled up in the depression."

The great northern and western land, termed by Dawkins, *Archaia*, whence came this mass of mineral deposits, occupied the North Atlantic sea, stretching from the west coast of Ireland and the Scottish Highlands to the American continent. To this great land may be traced the pebbles and groups of pebbles found in the Lancashire coal seams, mostly quartzites, which probably were brought down in flood time in roots of trees from the shingle beach.

Williamson,⁷⁰ in discussing the characteristics of the great fossil in the Owens college museum, remarked that that specimen had removed finally all doubts respecting the relations of *Stigmara* by showing that plant to be the root of *Sigillaria*. The roots divide only once and after division extend indefinitely. The stigmata are lacking near the stem because the roots increased by exogenous growth and the superficial portion with its rootlets was thrown off. The trees grew in swampy ground as the swamp cypress does in American swamps. The gymnospermous plants grew on drier ground. The particular tree under consideration must have been at least 100 feet high. When it died, decay continued downward to the point shown and then was checked probably because the lower portion was buried in sediment and protected from air. Thence decay proceeded very slowly until the woody tissue of even the root disappeared. Meanwhile, the surrounding rock had hardened and had taken a cast of the stem and roots. The surface sank beneath the water and soft sand filled the cavity; thus the roots have their original form.

Fayol, after spending many years in study of the basin of Commen-try, published his results in a remarkable work, which is un-excelled as a record of detailed observation. This work presented the grounds on which, several years before, its author had based his theory respecting the formation of coal beds. The positive position taken in favor of the transport theory and the clearness, with which the observations were offered, caused a notable reaction in favor of the doctrine that coal beds are formed of transported vegetable matter. A year after publication of the work, Fayol gave a summary of the delta theory, as he termed it, at the summer meeting of the Geological Society, when several members of the society commented on the theory. This resume, being the later presentation, is the basis of the present synopsis.⁷¹

The theory is based on the laws of sedimentation, as observed in

⁷⁰W. C. Williamson, "On the Fossil Trees of the Coal Measures," *Trans. Manchester Geol. Soc.*, Vol. XIX., 1888, pp. 381-387.

⁷¹H. Fayol, "Études sur le terrain houille de Commen-try," I^{re} partie. "Lithologie et stratigraphie." *Bull. Soc. Min. Ind. St-Etienne*, 2^{me} Ser., XV., Liv., III., IV., 1887; "Résumé de la theorie des deltas et histoire du bassin de Commen-try," *Bull. Geol. Soc. France*, 3^{me} Ser., XVI., pp. 968-978.

deltas. Mingled detritus brought in by streams forms a stratified deposit in the basin, where the beds may be composed of a single substance or of several. Those beds are inclined, irregular and of small extent in tranquil waters but less inclined and of wider extent in agitated water. The inclination may vary from 0 to 45 degrees; different portions of a bed may vary much in age, while beds at different levels may be contemporaneous. The total thickness of a deposit has no necessary relation to the sum of thicknesses of the beds which compose it, for a basin, 100 meters deep, may be filled with inclined beds which may have a total thickness of 1,000 meters; he gives illustrations of these conditions.

The little basin of Commentry is one of several isolated areas in a synclinal which is about 60 kilometers long. These are separated by granite and gneiss and the evidence shows that they were always separate. That of Commentry, 9 by 3 kilometers, contains only Carboniferous rocks, except at the northwest, where some Permian remains. The rocks are not disposed at hazard, but there are definite zones or areas, each with its own type of rock, and these areas, as it were, interlock laterally. Each contains detritus derived from a single locality, though there is a greater or less intermingling where the deposits interlock as overlapping wedges. The history of the basin is thus interpreted by Fayol.

A lake, 9 by 3 kilometers in area and 800 meters deep, was surrounded by steep mountains. Rainwater ate away the surface, digged valleys, carried to the lake pebbles, sands, clay and plant materials, by which at length the lake was filled. This was one of numerous lakes, depressions and alpine elevations on the central plateau of France. Sediment brought in by the streams was heaped up at mouths and formed deltas. The main stream at the northwest, the Bourrus, cut through the mica schist and reached the granite, the latter being found in the upper part of the delta. This delta has the steep slope, with pebbles, blocks, sand, clay and plant debris, all disposed in accord with the laws of delta deposit. A somewhat smaller stream, the Colombier, at the east, flowing over anthracitiferous beds and afterwards cutting back to crystalline rocks, formed another delta of similar type; while petty streams from the north formed

small intermediate deltas. Apparently nothing came from the south, where the waters found their outlet. As the deltas increased in size and approached each other, their elements intermingled.

The lighter materials, clay and plant, floated into a bay in the southeast corner, where they formed some beds of shale and coal, while in less degree, similar materials floated off on the other side of the Bourrus delta into the bay at the west, where, in like manner, deposits of shale and coal accumulated. Eventually the Bourrus delta divided the lake into two small ponds and in the larger were formed thin irregular lenticular beds of impure coal. At length the lake was filled up and streams began to destroy the coal formation. Disturbances set in afterward but they were not serious, for the Permian deposits are almost horizontal.

The facts to support this explanation of the origin of the beds, both mineral and vegetable, are presented abundantly in the great excavations. The walls show local faultings, thinning of *faisceaux* of beds, pebbles of coal are seen in several strata, a great lenticular parting, in part very coarsely conglomerate, occurs in the Grande Couche. This remarkable coal bed is only a few centimeters thick at the southeast outcrop, but it swells thence to 10 to 12 meters and retains that thickness along the outcrop for about 2 kilometers and a half, beyond which it becomes thinner and at length disappears. Followed down the dip, it decreases in thickness and disappears toward the depth of 350 meters. The outcrop resembles an open C and the interval from the outcrop to the old rock is 500 to 800 meters. Before disappearing at the west, the bed breaks up into six diverging branches. Two other beds, the *Gres noirs* and the *Pourrats*, are in contact with the great bed at the southeast but they diverge westward. Some lenticular deposits of anthracite occur at the base of the series in both bays.

Fayol made careful calculation of the quantity of vegetation which could be produced on the whole drainage area of the lake and asserted that enough be produced to give ten times the coal present—and this within the period of 17,000 years. This period is a maximum, corresponding to a very slow filling and to the minimum transportation of vegetable material. On the hypothesis of formation *in*

situ after the manner of swamps, he thinks a period of 800,000 years would be required.

Fayol's delta theory, then, is that the deep lake was filled gradually with material carried down by the streams; that this material was deposited according to its gravity, fine clay and vegetable matter being regarded as equivalents; the arrangement being that observed in deltas. It differs from the theory offered by Jukes by adding the suggestion of great original depth of the basin, a conception against which v. Gumbel had argued a number of years before.

The record of the summer meeting of the Geological Society was issued as a separate⁷² and it contains the discussions by several members. The doctrine as enunciated by Fayol was regarded by Busquet as applicable to the basin of Decize, by Nougarede as supported by much observed in the basin of Epinac, and by Bergeron as explaining the conditions observed at Grassesac and Decazeville.

Renevier⁷³ was not prepared to give assent to the doctrine and he suggested some grounds for hesitation. Vegetable materials in suspension are equivalent to fine mineral *débris*. If the coal beds were formed, as Fayol thinks, by the sweeping off of vegetable *débris* from the land and its deposition on the surface of the delta, that *débris* should accumulate on the border of the dejection cone, in the more tranquil waters, so that the deposit should have only a gentle original slope. But the great bed of Commentry has an extreme dip of 50 degrees, the same with that of the beds which accompany it. He regards these dips as impossible in a cone of dejection and suggests other modes of accounting for them. He maintained that the phenomena indicate, in part at least, the agency of marshy or semi-aquatic vegetation. Even the great thickness of the Grande Couche seems to him an argument in favor of vegetation in place, receiving increment brought in from the neighboring forests.

Delafond⁷⁴ was inclined to question the applicability of the doctrine without modification to the basins of the Saonë-et-Loire (those of Autun, Blanzay and Creusot). Fayol conceived the existence, before the coal deposition, of a deep depression transformed

⁷² "Réunion extraordinaire dans l'Allier," *Bull. Soc. Geol. de France*, 3^m Ser., XVI., 1890.

⁷³ E. Renevier, "Réunion, etc.," pp. 77, 78.

⁷⁴ F. Delafond, "Réunion, etc.," pp. 73-78.

into a lake, in which would be deposited, in form of a delta, the various elements which constitute the Coal Measures; the plants, giving the coal beds, would have been furnished principally by the luxuriant forests which grew on the alluvial plains of the deltas. During and after the formation of the Coal Measures, the movements of the crust were so unimportant as to leave no apparent trace, so that to-day one can easily find all the circumstances accompanying the formation of the deposit. But these were not the conditions in either the basin of Autun or in that of Blanzay and Creusot. There were important movements of the crust during and after the Carboniferous and the Permian.

In Autun the successive stages overlap in such fashion as to be explained only by admitting, during the process of deposition, the existence of crustal movements which modified profoundly the shape of the basin. Further, it would be difficult to explain by this doctrine why in Autun the important coal beds are in only the lowest part of the formation, at the time when the alluvial plains of the deltas were small; whereas, in the later part of the formation when those plains should have acquired great extent and could support immense forests, there were formed only some insignificant deposits in the Upper Coal Measures. Similarly in the other basins of the Saone-et-Loire, there were movements during the formation of the Coal Measures and of the Permian, which caused the overlapping of deposits.

Delafond recognizes that the process of delta formation explains the manner of deposit, the separation of the various materials, coal, shale, sandstone; but the intervention of movements of the crust is indispensable.

De Launay⁷⁵ remarked that it would not be incompatible with the theory of deltas to believe that movements of the crust occurred during the period of the Coal Measures and that they had given progressively the great depth observed to-day.

Almost at once after the appearance of Fayol's first publication, de Lapparent⁷⁶ gave his adhesion to the new doctrine. His first

⁷⁵ L. De Launay, "Réunion, etc.," p. 102, footnote.

⁷⁶ A. de Lapparent, "L'Origine de la houille," Assoc. Franc. Avanc. Science. Conférences de Paris, 1892. The same in *Rev. des quest. scientifiques*, Juillet, 1892.

publication was in 1887; in 1892 he presented his views in vigorous fashion. The statements are made with that clearness and precision which characterized his writings, so that it is well to give the synopsis in detail.

The early observers regarded coal as due to transported vegetable materials but the fascination of actual conditions, as exposed by Lyell, led men to abandon that explanation and to see in the vast peat bogs of this day the modern representative of coal beds. De Lapparent gives a synoptical statement of the peat bog theory. He thinks this doctrine deserving of a double reproach—it draws no argument from the nature of the coal itself⁷⁷ and it does not consider sufficiently the topographical conditions of each bed.

De Lapparent says that coal, especially in the great maritime basins, has wholly mineral aspect, laminated, with conchoidal fracture and showing no sign of organization; even thin sections show only amorphous material with rare indications of cellular structure. In most cases, chemical and microscopical examination must be combined, but sometimes the former is unnecessary. Fayol discovered at Commentry, in 1883, lenticular brilliant zones which proved to be flattened stems. Grand' Eury, in 1876, asserted that the coal of the Loire basin was formed of vegetable remains laid flat in a position uniform enough to suggest a liquid in repose. Several beds at Saint-Etienne consist wholly of *Cordaites* bark and the Grande Couche at Decazeville is composed of bark of *Calamodendron*. This determination, first made by Grand' Eury, is interesting as showing that the leaves, barks, etc., play in the coal the same part that vegetable imprints do in the shale. The ulmic matter, resulting from maceration of vegetable detritus, formed the sediment in which the recognizable remains were buried.

To explain the origin of this amorphous material, he quotes Saporta, who relates graphically the conditions existing in the dense forests of the hot, humid Carboniferous time. The rapidly accumulating mass of leaves, loose internal material from tree trunks, was

⁷⁷ It is well to remark in passing that de Lapparent's statement was made 54 years after Link's investigations, 33 years after Dawson's publications in the *Q. J. G. S.* and 9 years after publication of v. Gümbel's elaborate researches.

converted into ulmic material, the lower part of the deposit becoming a blackish paste. Detached heaps of leaves, peripheral sheaths of ferns, cortex of *Sigillaria*, *Cordaïtes*, etc., obstructed places at foot of slopes and awaited only the passage of waters in order to abandon to them the great mass of material in various stages of decomposition. This vegetable pulp is the amorphous gangue in which one finds the barks and leaves. But it is no longer in place. It shows evidence of having been suspended in water; the condition of the fragments shows that they have been subjected to frequent and energetic friction. By what mechanism was this transport effected?

Grand' Eury thought that the waters of great rains sweeping down the slopes drew the vegetable detritus into lagoons—such waters were limpid. At other times the streams carried muddy water with sand and clay giving sandstone and shale. Thus was explained the alternation of coal with other rocks. But de Lapparent cannot understand this selective process—the conditions are unlike those of the present day. The delta theory of Fayol is preferable and it applies perfectly to the lacustrine basins of central France. It is no mere hypothesis, but the result of long, painstaking observation in the great open quarries of Commentry. More, Fayol made experiments which proved that the conditions were such as must be due to delta formation.

The cause was gained and it remained only to answer objections offered by adherents to the old theory. The presence of vertical trunks was shown to be not only not inconsistent but rather consistent with the theory. And this was the most important objection. The presence of *Stigmaria* in the underclay is no objection. Those are rhizomas capable of giving origin to *Sigillaria*; when swept by torrential currents, they were drawn into the deltas, where being heavier they would pass to the bottom of the mass which was to become coal. The delta theory is full of important consequences. There is no further need of numerous and complicated movements of the crust. The beds have been deposited one on the other as sediments on the surface of a submerged dejection cone. If complete stability of the surface be one of the conditions of the phenomenon, there is at least no *a priori* reason to put it in doubt; as the beds had to be deposited

with a certain inclination, there is no need of calling in, for lake basins, dislocations to explain phenomena which may very well be primordial. The time required for the deposits is vastly shortened. Not only a complete coal bed, whatever its thickness, but also a portion of the underlying clay and sandstone, becomes before our eyes the product of a single flood. Fayol has shown also the rapidity with which vegetable matter is transformed into coal. The coal of pebbles in the rocks is coal, so that when a portion of the delta was exposed by a change in equilibrium of the surface, its coal suffered erosion as did the other rocks. De Lapparent finds in the study of Commentry some important matters bearing on the origin of the coal itself, which will be considered in another connection.

The coal of the maritime basins of France is a vegetable alluvium deposited in a delta; but the material has been brought from a greater distance and by the action of the waves it has been spread out over a greater area. In the central plateau the vegetable packets descended violently from the neighboring steep slopes to be deposited *en bloc* with pebbles of the torrent, thus producing some thick but very localized masses of coal. In the Nord area, there must have been, far above the mouth, wide river sheets in time of flood, many kilometers broad, like the Amazon and Orinoco, on whose surface the vegetable matter was spread. In subsiding, the ulmic materials, which formed the chief mass, separated themselves from the fine clays. This explains the constancy of the floor, while the roof may consist of any material. As the unmacerated vegetable matters, fronds and barks, had to float on the surface of the ulmic materials, one can understand why they are so abundant in the roof. The mouth of rivers changed their position, which explains the invasion of brackish waters. Thus is understood easily the filling of the old arm of the sea.

Why is it that a theory, so luminous, has not gained the adhesion of any but Frenchmen? De Lapparent thinks the hesitation due to lack of confidence in anything novel which comes from outside, and tends to overthrow notions so long accepted that they seem to be part of a national patrimony. Foreign doctrines are subjected to quarantine as foreign goods at a custom house. It is possible that

the hesitation is due to imperfect exposition of the doctrine at the outset, when Fayol declined to accept crustal movements as having had any influence; but that error was corrected afterward by Fayol. De Lapparent considers that to deny all influence of orogenic movements upon even the lacustrine areas would be excessive. Coal basins are depressions, feeble lines of the earth's crust, are landmarks of fractures whose equilibrium has been disturbed frequently.

Malherbe⁷⁸ notes that, though the explicit statement is not made, Fayol evidently regarded his doctrine as of universal application. But Malherbe asserts that, while it may suffice for Commentry, it cannot suffice for other basins. He utilizes the Liege basin as testing ground. That basin has an area of 40 by 15 kilometers, with 50 coal beds and numerous petty seams. The northerly border is but slightly disturbed; away from that the disturbances become serious and some of the faults extend through the formation, which is 1,200 to 1,500 meters thick. This is very different from Commentry, which is small in surface and depth, enclosing an insignificant number of beds. If the Commentry strata are in the original position, those of the Liege basin must be the same; but everything proves the contrary—the enormous displacements of the beds, the presence of *Cardium* in horizontal and inclined beds alike; all show original horizontal deposit. The waters from the Liege basin carry salt and Roget-Laloy has proved the same for the coal formation of the north of France, concluding therefrom that that is the sea water of the coal time imprisoned in the rocks. The deposit is not lacustrine but fluvio-marine.

Fayol's capital objection to theories other than his own is the apparent impossibility of periodicity in deluges due to terrestrial oscillations. Malherbe thinks it equally difficult to explain by Fayol's hypothesis the transport of a mineral formation, 1,500 meters thick and enclosing 50 coal beds from 0.45 meter upwards on an area comparable with that of modern seas—for the elevations breaking the area into basins came after the coal time. Oscillations are known in the present time, they are probable for other times. If one recognize that subsidences necessary for formation of beds

⁷⁸ R. Malherbe, "Géologie de la houille," *Ann. Soc. Geol. de Belgique*, T. XVII., 1890, Memoirs, pp. 25-40.

occurred only during accumulation of the great beds and that the overflows, bringing about the deposition of sterile rocks, led to transportation of vegetable matter intercalated in the intervals as veinettes, the number of overflows would be greatly reduced. Malherbe discusses Fayol's doctrine in detail and at the close expresses much doubt respecting its competence to explain even the phenomena of Commentry.

Renault⁷⁹ says that coal beds are intercalated among beds of sandstone and shale and, like those, they have all the features of deposits made in water. In sandstone, the fragments are inorganic and preserve the chemical as well as the mineralogical characters of the rocks whence they came; in coal, they are derived from plants and conserve the anatomical, at times, also the chemical characters of the plant organs. The fragmentary condition of these organs, the small proportion which they form of the mass, consisting chiefly of a blackish vegetable powder as gangue, show that the plants had been subjected to repeated energetic friction before their burial. So one cannot admit that coal beds were formed solely by accumulation, *sur place*, of debris from an exceptional vegetation, spreading over marshes, lowlands, lagoons, etc., near lakes or the sea; that the surface, subject to elevation and depression, saw, checked and again restored, that great vegetation of which innumerable generations would be represented by successive coal beds.

The fragments of wood and bark are very small. If the vegetable materials had been changed into coal and buried where their debris is found, it is certain that, in place of these reduced fragments, there would be entire trunks, branches and complete leaves as principal constituents of the mass. More, taking into consideration the diminution of volume, which vegetable tissues experienced in becoming coal, it is evident that numerous forests of high trees growing successively on the same place, would form hardly a few centimeters of compact coal—even though one suppose that, at the foot of the trees, there grew a mass of herbaceous plants. Further, the thick coal beds are separated by great deposits of sandstone or shale; as those deposits were formed slowly after the

⁷⁹ B. Renault, "Études sur le terrain houiller de Commentry," Livr. 2^{me} Flore fossile, Saint-Etienne, 1890, pp. 704-712.

manner of sediments, one must assign, if he admit this succession, an extraordinary duration to the coal epoch.

Renault accepts the explanation offered by Fayol and commends especially the shortness of the time which it requires. During the Carboniferous time, the air held more moisture than now, as no ice cap covered the polar regions; the rains were frequent and abundant; depressions occupied by lakes were filled rapidly. If one consider the strength of the torrents, greater than now, and the vigorous growth of vegetation, surpassing that of the present tropical regions, he will recognize that the formation in the Basin of Commentary could have been deposited in even less time than is required by the Fayol hypothesis. The selection, so distinct in deposition in inorganic materials, would take place with equal readiness in the plant materials. Coarse fragments, such as trunks, branches, would be dropped with the sand and clays, while the lighter, finer materials would be carried beyond into deeper parts of the basin.

Erect stems have little bearing upon the question at issue. Many of them are merely in-floated fragments, while those, which are *in situ*, do not penetrate the coal beds and have no relation to them.

Spring⁸⁰ undertook investigation along a new line. His study, though bearing largely on the question of transformation, finds place here because the results have an important bearing on the manner of accumulation. The homogeneity, the structure and composition of coal beds all seem to favor the doctrine of transport; but the stratification within coal beds does not exclude the doctrine of *in situ* origin, for with rare exceptions modern peat bogs show a structure resembling that of coal. It is clear that a definite conclusion respecting mode of formation cannot be reached by study of the coal bed alone; he determined to investigate the shales of mur and toit.

The mur of a bed formed by transport would be impregnated with vegetable matter to some distance below the coal while the toit should contain little. In the Belgian terrane, the shales of the toit,

⁸⁰ W. Spring, "Détermination du carbone et de l'hydrogène dans les schistes houillers," *Ann. Soc. Geol. de Belgique*, XIV., 1888, "Memoires," pp. 131-154.

when broken up by atmospheric agencies, yield a hard rather plastic material, resisting plant growth, yet they are as black as those of the mur. The theory of origin from peat would require that, in the mur, the quantity of carbon increase as it approaches the coal, as it must contain roots of plants; while in the toit the carbon should decrease gradually as one recedes from the coal. There is no abrupt change from coal to shale in the roof, so that the latter should be richer in carbon than the mur.

It is necessary to see how transformation of vegetable matter into coal is explained by each theory. This necessity is felt by defenders of the transport theory, because the flowing water furnishes only a mass of wood, bark, leaves whereas according to the theory of peat bog origin, the change of vegetable matter into peat is associated with the deposition.

In passing from vegetable matter to coal, there is great loss in hydrogen and great enrichment in carbon. Either the plant materials were changed into peat, lignite and the rest successively, or the organic matter was converted at once into its present state without passing through the intermediate stages. The latter explanation rests chiefly on Fremy's experiments, which showed that vegetable matter, subjected to high pressure and a temperature of 200° to 300° C. for a long time, becomes converted into a material very closely resembling bituminous coal. A fundamental objection to this theory is that no evidence exists suggesting that any such temperature prevailed, and nothing is less established than the conception that time could compensate for deficiency in heat.

However this may be, it is evident that, according to the doctrine of transport, the change going on in materials between the shales requires that specimens of shale collected at equal distances in receding from the coal, should show the carbon and hydrogen varying in a determinate manner; in proportion as one recedes from the coal the shale should have less of carbon and more of hydrogen as the more volatile hydrocarbons would go farther. But the doctrine of peatbog origin leads to a contrary condition.

A determination of the carbon and hydrogen in shales near coal beds may aid in answering the question as to whether the

hydrocarbons are impregnations from the forming coal or are due, as in the coal itself, to transformation in place of vegetable debris, imprisoned when the shales were deposited. These determinations would tell us if one should prefer the doctrine of transport to that of formation *in situ*, and whether the transformation of vegetable matter into coal has been accomplished by a kind of distillation or has been caused by a special kind of fermentation.

In the course of his studies, Spring discovered an unexpected condition—that the shales, containing organic matter, were the seat of slow oxidation, depriving them of hydrogen. The shales not only protected the coal from erosion but also from oxygen, as gas or in solution, the action of the oxygen being exhausted in the shales. As the encasing rocks are not the same everywhere, the character of the coal should differ in the same bed and in different beds. Usually, meager coals are on the peripheral parts of a basin while fat coals prevail in the middle portions. May this be because the latter have been better protected against the action of oxygen?

The shale samples studied were from the Saint-Gilles mine near Liege, eight of them, with one from the coal bed. Five were taken from the toit and three from the mur, each representing a vertical space of a half meter. They are marked "a," "b," "c," "d" and "e" for the toit and 1, 2 and 3 for the mur. The material was dried and analyzed with these results;

	Coal.	"a"	"b"	"c"	"d"	"e"	1	2	3
Carbon	86.61	7.54	3.35	2.21	1.20	0.70	0.99	0.93	0.80
Hydrogen	4.65	0.79	0.62	0.54	0.56	0.59	0.84	0.53	0.58
Ash	1.84	98.33	92.05	93.86	92.00	94.08	95.16	93.50	93.20
Oxygen, sulphur } by difference }	4.80	3.34	3.98	4.10	6.24	4.63	3.01	5.04	5.42

The carbon varies greatly but regularly, decreasing as one recedes from the coal. No conclusions can be drawn from conditions in the mur as the quantity is very small, but the variation in the toit is a logarithmic curve, the cause producing the variation is in inverse relation to distance from the coal. This seems to show that Fremy's conclusions are right and that the shales were impregnated with carbonaceous materials at expense of the coal, the com-

pounds less rich in carbon going farther. But the relations lead to a chemical impossibility; "a" gives C_8H_{10} , while the coal gives practically $C_{16}H_{10}$.

The reason is that not all of the water of hydration goes off at 120° . To escape this error, Spring employed hydrofluoric acid and continued the solution until the ash was about 10 per cent., the same with that of many coals. Analysis of the residues gave these ratios;

	"a"	"b"	"c"	"d"	"e"	1	2	3
C: H	24.80	30.45	36	?	?	19.80	?	?

The results for "d" and "e" are uncertain as are also those for 2 and 3, the hydrogen being present in such small quantity. Determining the absolute relation of hydrogen he has

	Coal	"a"	"b"	"c"	"d"	"e"	1	2	3
Carbon	88.61	7.54	3.35	2.21	1.20	0.70	0.99	0.93	0.80
Hydrogen	4.65	0.30	0.11	0.06	?	?	0.05	?	?
C: H	19.09	24.28	30.45	36.00	?	?	19.80	?	?

The relation of carbon and hydrogen in the mur is very nearly the same as in the coal; it contains particles of coal little altered. But the toit results are remarkable; the hydrogen diminishes in relation to the carbon and in "d" and "e" it is no longer in appreciable quantity. Evidently the roof shales are not impregnated by volatile materials coming from the coal, as required by Fremy's theory. The transformation of the vegetable matter is rather by ulmic fermentation. Within the primitive marshy mass the plant substances have yielded ulmic materials while becoming richer in carbon. These have impregnated the whole and have been modified by external agencies.

The doctrine of transport seems to be out of harmony with the results as by it one would have difficulty in explaining the richness in carbon characterizing the toit. The alluvium, because of its physical nature, could not support a sufficient vegetation. If one suggest that the alluvium at its origin was mingled with much vegetable debris, it may not be superfluous to ask if the plants could remain on slopes, denuded and torn up by the flood which had swept away the most thoroughly rooted plants. Everything speaks of origin *in situ*. But returning to the analyses.

If the alluvium covering the peat bogs came gradually it would be mingled with a greater or less quantity of vegetables, which had to undergo the same changes as the underlying mass in order to become coal. One ought to find in the alluvium the same proportion of carbon and hydrogen as in the coal itself, or at least nearly so. If this relation do not exist, evidently some external influence has been exerted. And the relation does not exist; the variation increases as one recedes from the coal; this irregularity must be due to some slow action becoming appreciable through lapse of time. Everything seems to indicate that slow oxidation went on in the shales, acting chiefly on the hydrogen, for which oxygen has the greater affinity, so that it has converted the vegetable matter into anthracite in the more distant part of the shales.

According to this conception, coal with abundant gas could have been formed only when the material was protected against atmospheric agencies. The many varieties of coal owe their origin rather to unequal degrees of protection; the fattest coals give off the most abundant grisou—evidence that the enclosing rocks are impermeable.

Wild⁸¹ in describing the Lancashire coal-field, referred to the "bullions" which are characteristic of the Mountain-Four-foot coal bed. These, embedded in the coal, are ferro-calcareous "concretions" more or less pyritous, frequently enclosing mineralized wood, "showing the woody and cellular structure of the plants which have produced the seams of coal from which the concretions are extracted." Shells are absent, the nodules being for the most part fossil wood in varying degrees of preservation. The coal bed is persistent and its roof shale contains concretions, known as "baum-pots," which at times are embedded partly in the coal. These are ironstone or calcareous, sometimes weigh 40 pounds and contain marine shells but rarely any wood.

After a review of all the coal beds he considered the question of their formation. The generally accepted theory that coal comes from growth *in situ* seems to be a natural conclusion, for the roots in the underclay pass through several layers. It is true that under-

⁸¹ G. Wild, "Lower Coal Measures of Lancashire," *Trans. Manchester Geol. Soc.*, Vol. XXI, 1892, pp. 364 et seq.

clay is not essential for vegetable growth, but more than three fourths of the coal beds have it. The "bullions," composed of fossil wood, occasionally show rootlets working their way through the decaying wood, separating the fibers which now surround them. The fossil wood is often parallel to the bedding of the coal, a condition familiar in prostrate forests and in peat accumulations. Erect trunks and stems are unusual both in coal and peat. The underclay was the land surface which supported vegetation like the forests of swamps where warmth and moisture prevail.

If coal is to be considered as derived from drifted material, he is puzzled to discover what has become of the shells and fishes, which must have abounded in the tracts of water in which the deposits were laid down. To float some of the large trees either vertically or horizontally, with their outspread roots having a radius of 15 to 20 feet, would certainly require enough water to accommodate fishes and mollusks. Remains of fishes are not necessarily destroyed by embedding them in coal-forming material, and shells are as capable of resisting destruction as fish spines are. Shells and fish remains occur often in impure cannel. The "bullions" have yielded no shells, and fish remains are very rare in pure coal. That the trees were forest growth is proved by the splendid specimens in the Manchester and other museums.

Estuarial swamps with intermittent subsidence, permitting deposition of sand and mud, would explain alternations of coal and other strata, whichever theory of coal accumulation be accepted. Marine conditions frequently followed directly upon formation of a coal bed; fishes of shark-like types are in shales directly overlying coal at many horizons. But shells and fish are unknown in the underclay.

Orton,⁸² in his description of the coal-fields of Ohio, considers the various theories of formation; some of them appear to be based on merely local conditions, others are extravagant and only a very small proportion of the explanations seems to have been the result of careful observation in extensive areas.

In a coal-field, one finds a system which can be explained only by subsidence. Limestone is found above and below coal beds and

⁸² E. Orton, *Geol. Survey of Ohio*, Vol. VII., Antioch, 1893, pp. 256-262.

is accompanied by iron ore. The coal beds, though variable, are wonderfully persistent and are always associated with fireclay. There is no haphazard mode of occurrence. Coal is product of land life; limestone is of marine origin; the ore depends on life for concentration; sandstone, occupying the intervals between other rocks, is due to inorganic forces and it may be about equivalent to the others. Orton's conclusions based on more than twenty years of study in much of the Appalachian basin, are:

(1) The Ohio coal-field, at the beginning of the Carboniferous, was an arm of the sea with the Cincinnati arch as the western boundary. (2) Marginal swamps of varying width became the earliest coal seams by long continued growth and subsequent fossilization. (3) While the swamps were submerged, in succession, and covered by shale, sandstone or limestone, in turn covered by other swamps, the continental nucleus grew slowly at the south and the Cincinnati arch united with it by like advance eastward, expelling the waters of the gulf and converting the earlier formed portions of the coal formation into dry land. (4) Every coal swamp had a narrower area than its predecessor. (5) As all coal seams were formed at sea level, so all were raised by continental growth to an approximate equality, which their outermost outliers still retain. (6) To look for the earlier formed seams in the center of the basin would be to look for the living among the dead. (7) In the formation of one seam, in particular, the floor of the gulf, around which the swamps were growing, seems to have been raised nearly to sea level at many points, and coal appears to have been formed in island-like masses over much wider areas than any single marginal swamp would account for.

Bolton⁸² describes a peculiar deposit of coal in Ireland. The Jarrow coal bed appears to be a great cake, attaining a maximum thickness of 16 feet and thinning in all directions except toward the west, in which direction no tests have been made. Underclay is absent at almost all localities. The lower part of the deposit is a smutty anthracite with slaty structure and containing abundance of

⁸² H. Bolton, "Notes on the Plant and Fish remains from the Jarrow Colliery, Co. Kilkenny," *Trans. Manchester Geol. Soc.*, Vol. XXII., 1894.

Lepidodendron stems. The upper part is a pure typical anthracite. Fish remains, *Gyranthus*, *Megalichthys*, etc., occur throughout. The plant remains are *Halonia*, in the form of crushed cylinders of wood. This condition and the mingling of fish remains led Bolton to conceive that the deposit was due to the bursting of a lagoon-like swamp and to the discharge of vegetable debris, consisting of bottom accumulations as well as of the twigs, etc., on the surface. He refers, for illustration, to the bursting of Solway moss in 1771, which spread over a square mile of ground, giving a mass of vegetable matter, 30 to 40 feet deep, demolishing houses, overturning trees and so contaminating the Esk that no salmon ventured into the river during that year.

Kuntze⁸⁴ took up the discussion from a botanist's standpoint and advanced a wholly new theory. He antagonized v. Gümbel's conclusions which he maintains are wholly at variance with that observer's facts. His own studies from 1879 to 1883 had shown that the Carboniferous flora was sylvo-marine, a floating vegetation. The objection that marine forms are wanting does not hold good: the forms, described by v. Gümbel as resembling algae, are chitinous bryozoans related to *Aulopora*. These, as stated by v. Gümbel, occur abundantly in cannel and make up a great part of the boghead coals. Carboniferous coals contain much sodium chloride, one fourth to one half kilogram per ton; Tertiary coals contain none. It is certain that the Carboniferous coals are not allochthonous; the flora must have been marine.

He contends that students have failed to interpret *Stigmaria* rightly, for the appendices, regarded as rootlets, are water leaves. The *Stigmaria*, with intertwining rhizomas and hollow stems rising above the water, formed floating islands. When overloaded, they sank to the bottom and through the mud until checked by some harder rock. He agrees with Potonié's conclusion that they are not allochthonous but he cannot concede that the underclay or clay shale is a petrified humus, for the clay is no more a soil than are the granite and other silicious rocks with which coal beds are often in

⁸⁴ O. Kuntze, "Geogenetische Beiträge," Leipzig, 1895, pp. 42-77. Sind Carbonkohlen autochthon, allochthon oder pelagochthon?

contact. The thickness and extent of some coal deposits are serious objections to growth *in situ*. Richthofen describes a bed in China, 20 to 30 feet thick and having an area of 600 German square miles. This would require at least 400 feet of plant remains. The bottom three feet might have been a soil in which *Stigmara* rhizomas could have grown, but the sturdiest defender of autochthony would be at loss to find a soil for the remaining 397 feet. Such a deposit could have been made only by a matt of sylvo-marine vegetation.

All allochthonous and land basin theories are untenable because transportation yields no undisturbed sedimentation; there is no transportation of organic detritus without contemporaneous transportation of inorganic material—the transportation of purely plant detritus is a superstition; subsiding land basins giving 7,000 meters of Carboniferous rocks, while neighboring basins subside at different rates, would be a marvel, for in order to account for the thick mineral beds the process of coal making would have to be intermitted a hundred times; there are no basins so great as those of coal sedimentation. The four great deltas do not equal the Pennsylvania coal-field alone; Richthofen's southeast Shansi field would require a basin sixteen times as large as the Caspian sea. The great basins must have been sea basins and a sylvo-marine forest alone explains the intermittent deposit of coal, the clays being due to influence of streams.

Kuntze classifies the theories as Autochthony, the irregular deposit of the coal-producing substance directly on the place of vegetation; Allochthony, the irregular deposit of coarse coal-producing substance on a distant place; only the powdery substance is deposited after the manner of sediments.

Pelagochthony, the sedimentary deposit of coarse substance in water of the sea directly under the vegetation; a secondary product is the powdery detritus sometimes floated away from the coal magma and deposited elsewhere as anthracite.

Autochthonous types are found in tropical or subtropical brown coal from wood-covered bogs, without sphagnum; newer peats in cooler regions with sphagnum; shore swamps and some others.

Allochthonous types are drift woods; sedimentary peats; sea

peat; paper peat, which is a bituminous clay with infusoria; Blatterkohle, a marly clay with a little sedimentary peat.

Pelagochthonous types are: (1) Normal Carboniferous coal fields. The coal beds have originated from floating forests and remains of rooted trees occur in very limited localities. Naumann's paralic coal-fields belong here; they are found in America, China, etc. (2) Sea basin deposits, consisting of limited but often very thick beds, the coal frequently thinning seaward; these contain, besides sylvo-marine remains, abundant remains of trees rooted in clay. Best seen in France. Here, in part, Naumann's limnic basins. (3) Amorphous anthracite, consisting of the finest detritus and forming irregular deposits; does not include Faser-, Staub- or Koksanthracite coal.

Penhallow⁸⁸ has given the results obtained by study of cannel-like coal from the lower Mesozoic of British Columbia. All the samples are composed of rod-like bodies more or less closely compressed, which resemble dark amber and are embedded in a cementing material. The rods show tubules within, many of them branching, which are very suggestive of *Mycelium*; granulations are common and often form zones around hyaloid areas. The features revealed by the microscope are:

(1) Absence of structure, (2) tubular ramuli of diverse dimensions, (3) rounded cavities, (4) large proportion of material in angular fragments and resembling that of the rods, (5) an amorphous substance, associated with (4), occurring as distinct flakes or as cement to unite the rods.

Appearance of structure was observed in only one rod and in that case it is evidently due to shrinkage; he thinks the spore-like aggregations are of chemical rather than of organic origin. The general character of the ramuli at once suggest *Mycelium*, but the intimate features and the arrangement forbid reference to vegetable structure. They rather resemble effects of internal shrinkage, following hardening of the outer layer, such as one sees in amber and other resins. The material occupying spaces between the rods and

⁸⁸D. P. Penhallow, "A Preliminary Examination of So-called Cannel Coal from the Kootanie of British Columbia," *Amer. Geologist*, X., 1892, pp. 331-339.

apparently cementing them "consists of an amorphous and irregular mass full of rounded holes, thereby giving it a spongy character." It contains fragments of perhaps broken rods, the material in both being the same. The source of the amorphous material is not certain.

Penhallow offers no positive hypothesis respecting the origin of these coals, though he is inclined to think that it must be "sought elsewhere than in modified vegetable structure." At the same time, he feels that the evidence is not sufficient to justify the assertion that they did not originate in vegetable structure.

In 1892 and 1893 there appeared papers by Bertrand and Renault describing Bogheads and related types. Afterwards those observers published their results independently. The later studies of Renault concern the matter in hand only indirectly and they will receive consideration in another portion of this work. It is necessary, however, to make detailed reference to Bertrand's contributions, for, though they consider similar topics, the conclusions have a notable bearing on the formation of coal beds; and in this connection, the stratigraphical relations of the several types must be given. Without that one cannot appreciate the full bearing of the studies. The joint study by Bertrand and Renault⁸⁸ was of boghead obtained from Permian beds at Autun, France. This deposit occupies an area of 7 kilometers by 150 to 450 meters. The chief constituent is a thallophyte, *Pila bibractensis*, which makes up about three fourths of the mass; the remaining fourth being the "fundamental material" with some clay. Vegetable débris is wanting, but pollen of *Cordaïtes* and remains of fishes are present.

These observers recognized the bodies of yellow, red and other tints, which had been mentioned by earlier students, but their study proved that "certain resin-like bodies represent the organic gelose and even entire organisms. A great proportion of the yellow and red bodies enclosed in coals are in this category and M. P. F. Reinsch has the great merit of making this known." The inferior gelatinous plants have been preserved in this way when buried in

⁸⁸ C. Eg. Bertrand et B. Renault, "Pila bibractensis et le boghead d'Autun," *Bull. Soc. d'Hist. Nat. d'Autun*, V., 1892, Separate, pp. 95, pl. 2.

ulmic materials. The Autun boghead, 24 to 25 cm. thick, is not an accumulation of resinous pellets due to injection of hydrocarbons into plant débris, but it consists of 1,600 to 1,800 beds of algæ, which sank to the bottom along with grains of pollen and the fundamental material as well as the detritus. The fundamental material is brown, rather flocculent and feebly colored. It is a precipitated brown substance analogous to the ulmic matters which color the Amazon and certain of its affluents. It contains particles of a darker material, thelotite, an infiltration which penetrates the thalli.

The Pilas were algæ of very low type. Their isolation in the fundamental material, their accumulation in beds, with traces of pressure on the under surfaces, suggest that they were floating algæ like the *fleurs d'eau*. The pollen grains, usually reduced to their coats, were a powder resting on the water with the *fleurs d'eau*. The accumulation, which may have been very rapid, was only an incident in the formation of bituminous shale. It was made in quiet waters, with little or no current, and so rapidly that putrefaction could not begin in the mass. The deposit was laid down probably in shallow brown waters, like those of the Amazon region, whose acidity is unfavorable to development of many bacteria. Nearby, were forests of *Cordaites*, which furnished the pollen.

The second paper by the same authors⁸⁷ gives results of study of the so-called kerosene shale of New South Wales, which had been utilized as a source of gas and illuminating oil. This shale, known as Hartley mineral, Wollogongite and, in some reports as Torbanite, is of uncertain occurrence. Mackenzie⁸⁸ says that the deposits are very irregular, there being no guide to discovery except the presence of fragments at or below the outcrop. Toward the border of a mass, the rich mineral becomes deteriorated and gradually passes into indurated clay, bituminous or non-bituminous shale, coal or ironstone. It occurs at two horizons, in the Permo-Carboniferous of New South Wales, the most notable deposits being in the Upper Coal Measures, including the well-known areas of Hart-

⁸⁷ C. Eg. Bertrand et B. Renault, "Reinschia australis et premières remarques sur le kerosene shale de la Nouvelle-Galles du Sud," *Bull. Soc. Hist. Nat. d'Autun*, VI., 1893. Separate, pp. 105, pl. 7.

⁸⁸ J. Mackenzie, Ann. Rep. Dept. of Mines for 1896, p. 100.

ley, Joadja creek and Wollongong at the south and Murrurundi (Doughboy hollow) at the north. The only important deposit in the Lower Coal Measures is at Greta near Newcastle in northeast port of the province.

Long ago, Clarke⁸⁹ recognized the close resemblance of this mineral to the boghead or Torbanite of Scotland. He thought it due to local decomposition of some resinous wood and believed that the lens-form of the deposits and their passage laterally into shale could be explained easily by supposing the mineral to be due to drifted resinous trees, undergoing changes in shallow pools surrounded by material changing into ordinary coal. The quartzose constituents are merely sand carried by wind into the pool. The thickness of the deposit depended only on the supply of drift timber.

Wilkinson⁹⁰ says that the kerosene shale occurs in irregular lenses, sometimes in actual contact with layers of coal as at Joadja creek, sometimes wholly unassociated with layers of coal, as at Hartley, or even as forming part of a great coal bed, as at Greta. At the last locality, the boghead is a great lens in the coal, but there are many petty lenses of the same material scattered through the coal benches. At Joadja, one finds small irregular patches of bright jet-like material, plant remains lying horizontally and numerous vertical stems of *Vertebraria*, whose lustrous bright jet substance is in contrast with the dull luster of the shale.

David⁹¹ found the shale in one place at the bottom of a great coal bed; Mackenzie⁹² found it at the top in another; while in still another David found a mass of alternating coal, clay and "shale," five beds of the boghead and four of bituminous coal. At the last locality the whole mass thinned out in one direction, the several layers disappearing in succession until the last layer of boghead passed into bituminous shale. There he saw many stems of *Vertebraria*, both vertical and prostrate; in one tunnel, some of them four

⁸⁹ W. B. Clarke, "Mines and Mineral Statistics of New South Wales," Sydney, 1875, pp. 179-180.

⁹⁰ C. S. Wilkinson, "Mines and Min. Stat., 1875," p. 131; Ann. Rep. Dept. Mines, 1884, pp. 149, 156; 1890, p. 208.

⁹¹ T. W. E. David, Ann. Rep. Dept. Mines, 1888, p. 170; 1890, pp. 221-224; 1892, pp. 159-163.

⁹² J. Mackenzie, Rep. 1895, p. 104.

inches in diameter were converted into coal. Mineral charcoal is abundant in a mine in Camden County, while at Murrurundi the boghead "contains numerous fragments of mother-of-coal and small fragments of what appears to be coniferous wood like *Araucaria*, together with coniferous fruit."

In the pages already cited, David gives ten analyses by Mungaye, which show that at Murrurundi the ash varies from 17 to 68 per cent. and the fuel ratio from 0.11 to 0.24; while at Ketoomba eight analyses show ash from 10.7 to 78.1 and the fuel ratio from 0.13 to 1.10. A specimen from Joadja Creek had 77 per cent. of silica in the ash.

The material studied by Bertrand and Renault consisted of two great blocks, one in Paris and the other in Brussels, each more than one meter thick, apparently the full thickness of the deposit. Like the Autun mineral, the kerosene shale consists of a fundamental brown, flocculent material, holding algæ and remains of dead plant tissues. The algæ are assigned to the genus *Reinschia*, now extinct, but belonging to a group which was spread widely during Permo-Carboniferous times. The algæ are all separate, though, at times, owing to paucity of the fundamental matter, they are in contact, they are still independent. They were free, floating on the surface of absolutely tranquil brown water, and they rained down upon the bottom, while at the same time, under the influence of calcareous waters, an ulmic jelly was precipitated to form the fundamental material. The great specimen in the Paris Museum shows 36,000 beds of these algæ, but the proportion of algæ varies in the several layers from 0.019 to 0.900 of the whole mass. At Joadja creek the mineral is often beautiful, with a satin-like homogeneous surface, and it consists almost wholly of the algæ.

Infiltrations are here as at Autun. The most important is red-brown, in strings or sheets, and shows fluidal structure; it is harder than the fundamental material; it often impregnates leaves and wood; some plants have the property of absorbing this to a notable extent. Its mode of occurrence and its tendency to penetrate the substance of plant remains suggest great resemblance to the thelotite of Autun. The authors make no attempt to decide respecting the

source of this infiltration; they are convinced that it penetrated the deposit, if not contemporaneously, at least very soon after its formation and they suggest that it may be a kind of asphaltum, like that of lake Brea in Trinidad. The kerosene shale contains no animals except at Murrurundi, where some coprolites have been discovered. It is a charbon produced by unaltered gelosic organisms.

Bertrand's²³ later studies were published in a series of papers, his conclusions being summed up in a memoir presented to the Geological Congress at Paris in 1900.

The bogheads, typified by deposits at Autun of France, the Torbanite of Scotland and the kerosene shale of New South Wales are charbons gelosiques of Bertrand, accumulations of fresh water algae in a humic jelly, their fossilization being in the presence of bitumen. The basal material of all is a clear brown fundamental jelly, the dull part of the bogheads and the same as the basal material of v. Gümbel's Mattkohle. Spores and pollen have undergone maceration, but they did not liquefy. They gave two kinds of yellow bodies and they condensed bitumen strongly. When they abound, the coal, though dull, is brighter than mattkohle. Débris of vegetable matter, also a contribution by the wind, is distributed irregularly. The hardened tissues are usually brilliant, prismatic like v. Gümbel's Glanzkohle. Wood and barks can be found as brilliant coal, but this depends less on their organic nature than on the extent of alteration and their capacity to imbibe bitumen. Vegetation along river banks yielded tree-trunks, which, after imbibing bitumen, were converted into bright coal.

The algæ were *fleurs d'eau*. They consisted of gelose and a little protoplasm, which, when humefied, would condense bitumen. They descended in sheets with other accidental bodies; in times of low water, the descent would be very slow, being impeded by the

²³ C. Eg. Bertrand, 1, "Nouvelles remarques sur le kerosene shale de Nouv. Galles du Sud," *Bull. Soc. d'Hist. Nat. d'Autun*, IX., 1896; 2, 3, "Conférences sur les charbons de terre," *Bull. Soc. Belge de Géol.*, etc., VII., 1894; XI., 1898; (4) Caractéristiques du kerosene shale," *Assoc. Franc. pour l'avancem. des Sci.*, 1897; (5) "Les charbons humiques et les charbons de purins," *Trav. et Mem. de l'Univ. de Lille*, VI., 1898; (6) *C. R. du Congrès Int. de Géol.*, Paris, 1900, pp. 458-497.

fundamental jelly. Each ball of gelose yielded a little mass of glassy, transparent gold-yellow hydrocarbon.

The bituminous matter found in all is wholly different from the fundamental material. There is proof of its intervention, for it follows clefts made by contraction of the fundamental material, which it does not color. The coalified stems of *Vertebraria* on Joadja creek are humefied vegetable material charged with bitumen. There is no evidence that this bituminous enrichment was due to condensation of resinous matter held in suspension by the fundamental material; nor is there any evidence that the fundamental material originated from alteration of the enclosed bodies.

The accumulation could be made with remarkable rapidity. A few good days with low water would suffice. All the accidental bodies, enveloped in a humic coagulum, make a raft on the absolutely tranquil water. A very slight cause, colder weather, more water, would hinder formation of gelose and cause descent. The precipitation of brown matter was continuous but formation of gelosic matter was fortuitous; with check of algal growth, the deposit passes over to a humic coal or organic shale. The vegeto-humic deposit was fixed at once and remained unaltered. The fossilization was in the presence of bitumen, which became altered so as to be insoluble in the ordinary solvents of asphaltum.²⁴

Bertrand's charbons humiques differ from the charbons gelosiques in that the fundamental matter is not diluted with foreign bodies. They are typified by the Broxburn shales of Scotland, containing, according to Cadell, about 75 per cent. of ash. Accidental bodies, such as algæ, spores, pollen, vegetable débris are in small proportion. Bitumen penetrated through the fundamental jelly and enriched the shale. Bertrand finds no evidence that this bitumen is a leakage or exudation from a fermenting vegetable mass; he believes that it was in the water and that it penetrated the accidental bodies only with difficulty.

²⁴ After the memoir was read in the Paris congress, de Lapparent asked what is to be understood by the term "bitumen." Bertrand replied that "the term bitumen implied for him the idea of a substance charged with carbon and hydrogen, intervening wholly formed in the rock."

Gresley⁹⁸ called attention to the persistence of slate partings in the Pittsburgh coal bed as having an important bearing on the origin of coal beds. Two of them, one fourth to one half inch thick and separated by 3 to 4 inches of coal, are present in an area of 15,000 square miles. Under the lower one is a coal bench somewhat more than 2 feet thick, while above the upper one is a bench varying from 3 to 5 feet. The clay of the thin binders or slate partings is extremely fine grained, mottled, non-plastic, contains macrospores and indefinite plant remains, but no *Stigmaria*.

Accepting in full the doctrine of transport, he assumes that, at the close of deposition of the lowest bench, that mass of vegetable matter lay practically level on the bottom of a vast lake or inland sea. Such being the condition he finds difficulty in explaining the overlying shale as due to fine material brought in by currents; the shale is uniform in thickness and composition over a great area, so that the supply of material must have been uniform throughout; there could have been no changes in currents or offshore conditions during the period of deposition. The quantity is not less than 100 tons per acre. He finds equal difficulty in the suggestions that the shale consists of wind-blown dust, that it is a precipitate from solution, that it is concretionary. The supposition that these shales are substitution or replacement formations or that there was a segregation of inorganic substances during solidification or the process of coal-forming involves serious difficulties. "To suppose that such shale bands were originally thin films of chalky mud, since chemically converted into silica, alumina, iron, etc., would, I think, be exceedingly unsafe." At the same time, he suggests that the globigerina ooze, widespread "over the bottom of the Atlantic, where deepest and farthest from land would seem to furnish us with about the only way (as to physical conditions) in which our shale binders in the 'Pittsburg' coal bed can be imagined to have accumulated."

If the lower slate binder was really deposited as silt by aqueous transportation, the interesting query presents itself, How could the succeeding 4 inches of coal be formed *in situ*?

⁹⁸ W. S. Gresley, "The Slate Binders of the Pittsburgh Coal Bed," *Amer. Geologist*, XIV., 1894, pp. 356-395.

The Pittsburgh coal bed thickens toward the southeast and the slate partings, as well, thicken in that direction. The evidence favors the assumption that the organic as well as the inorganic materials came from the land surface in that direction. The absence of *Stigmaria* casts reasonable doubt upon the hypothesis of formation *in situ*, and this doubt is increased by the discovery of an aquatic fauna in the underclay of the bed, which Gresley has found to be a calcareous shale.

The extraordinary uniformity of the Pittsburgh coal bed in purity and structure, the evenness and geographical extent of its several divisions make it the most remarkable known. In explanation of its phenomena, about all that can be said safely is "that, everything being horizontally stratified, every part of it was most likely accumulated under water. I have therefore come to the conclusion that this coal is the accumulated remains on the bottom of a lake or sea of vegetable growth of *aquatic forms* (though much of it did not necessarily grow *in* the water) living afloat and dying and decaying, falling through the water." All the familiar phenomena can only be explained by an aqueous origin for the coal.

The problem of coal accumulation attracted Potonié's attention in 1886 but he published no results of direct study until 1895.⁹⁶ In that year he had opportunity to study a core obtained in the Upper Silesian coal field. This core, 750 meters long, one to 2 decimeters in diameter, begins in Saarbruck beds and ends in the Upper Ostrau deposits. As submitted to Potonié, it was complete and it was studied by him in company with C. Gaebler of Breslau. The core shows not less than 27 coal beds, each of which is in direct contact with a *Stigmaria* underclay; in most of them, remains of *Sigillaria* are present and some contain *Lepidodendron*—particularly in the accompanying carboniferous shale.

Ochsenius, who urged the allochthonous origin of coal beds, explained cases, such as are present in the core, as due to local subsidences and thought them of rare occurrence. But Potonié, as an outgrowth of broad observation, asserts that these cases are

⁹⁶ H. Potonie, "Ueber Autochthonie von Carbonkohlen-Flötzen und des Senftenberger Braunkohlen-Flötzes, *Jahrb. d. k. preuss. geolog. Landesanstalt für 1895*, pp. 31, pl. 2.

merely illustrations of the ordinary conditions. "The allochthonous formation of fossil humus beds is not the normal, as Ochsensius maintains, but autochthony is the normal, exactly as in the corresponding beds of the present day." But this does not exclude contributions from other localities. He cites the abandoned ox-bows of the Mississippi, into which drift wood is thrown at high water, but which are filled eventually with autochthonous peat in which the driftwood is enclosed. The existence of *Stigmaria* in intervening beds is a normal thing and to be expected, as appears from conditions in cypress swamps of North America. Its existence in the coal itself is explained by autochthony, for, on that hypothesis, the old decaying vegetation becomes soil for the new. Indeed, the only difference between deposits of the several geological periods is in character of the vegetation, there is none in the mode of accumulation.

He finds a fossil swamp of the American type in the Miocene deposits of brown coal at Gr. Raschen near Senftenberg, which contains, among other plants, *Taxodium distichum*. The brown coal is 10 meters thick and shows several generations of forests, one above the other, the stumps remaining rooted in the brown coal. Every feature of recent swamps is reproduced there except that the humus has become brown coal. Many of the stems are hollow, containing more or less of Schweelkohle. It is worthy of note that an old peat bog exists on the clay overlying the brown coal, and that, in the humose sand covering the peat, there are trunks of *Pinus silvestris*: the conditions favoring accumulation of humus continued there until diluvial time. The Schweelkohle is due to resinous exudations from broken parts of the tree—the familiar process of closing wounds.

Absence of stumps in no wise proves allochthonous formation. If the fossil moor had borne only non-resinous dicotyledons, the Gr. Raschen condition could not have come about. The fact that *Stigmaria* are often filled with sand is no evidence of allochthony, for hollow alder stumps in West Prussia swamps, exposed to high water, are filled with sand even to the roots, so that they must be cleaned out before the axe is applied.

In a later paper,⁹⁷ Potonié says that having supported the cause of autochthony, he must describe a deposit of allochthonous type. The distinctions are simple; in plants of autochthonous origin, the more tender parts are preserved but they are practically wanting in those of allochthonous origin. In connection with coal beds one has to do chiefly with autochthonous plants; but in Culm localities he has to do with "Haecksel," shreds of plants, which are characteristic of allochthony. These fragments are at time large enough to show by their arrangement the direction of the transporting current.

Allochthonous deposits of carbonaceous material have few botanically recognizable plants; many stems and branches, often coal coated but with surface sculpture so obscured that determination is impossible; stems of the *Knorria* type are of frequent occurrence; while *Stigmara* is almost wholly absent, those which do occur being imperfect. Sub-surface organs can be carried away only after having been washed out from their place: other portions of plants must be the essential material of a transported mass.

He presents the following contrasts.

<i>Autochthony.</i>	<i>Allochthony.</i>
1. Coal beds common.	1. Coal beds are.
2. Haecksel deposits absent or insignificant.	2. Plant remains prevailingly Haecksel.
3. Determinable plants numerous, especially in roof.	3. Few determinable plants; if coal bed, Haecksel in the roof.
4. Few indeterminable casts.	4. Indeterminate casts abundant.
5. <i>Knorria</i> rare.	5. <i>Knorria</i> abundant.
6. Abundant <i>Stigmara</i> in the liegend. With their appendices.	6. <i>Stigmara</i> absent or rare; they are without appendices.
7. Excellent preservation of ferns.	

Potonié presented a brief systematic discussion of the whole

"H. Potonié, "Die Merkmale allochthoner palaeozoischer Pflanzen-Ablagerungen," *Naturwiss. Wochenschrift*, XIV., 1899, pp. 81, 82.

PROC. AMER. PHIL. SOC., L, 198G, PRINTED APRIL 26, 1911.

subject in 1905;⁹⁸ since that time, in successive editions, he has widened the scope of his inquiries until, in the fifth, the presentation covers every phase with abundant illustration from German areas and references to those of other lands. Only certain portions of the work can be referred to in this place but, farther on, many citations will be made. He approaches the subject from the double standpoint of stratigraphy and palaeobotany.

The coals and allied substances are termed Kaustobiolithe, because they are combustible rocks of organic origin. He groups them into—

Sapropel deposits, originally “stinking muds” composed of aquatic animals and plants,

Humus deposits, derived from land plants.

The former include the cannels, the oil shales and, as a derived product, petroleum; the latter include the ordinary brown and stone coals. The difference in origin of the two groups is evident from the physical composition shown by the microscope as well as by the chemical composition, the Sapropels yielding compounds of the paraffine group while humus deposits yield compounds of the benzol group. The Sapropels are formed in quiet, almost or wholly stagnant water and are of limited extent; whereas the humus deposits were formed as are the moors of to-day and are of vast extent. He illustrates the modes of origin by description of a great bog in northern Germany, which exhibits the passage from sapropel muds at its shore, to the Flachmoor, well wooded; thence by the Zwischenmoor, with changing type of trees, to the Hochmoor, hour-glass in form, which is treeless except alongside of rivulets. He compares the conditions with those existing in sapropel and humus deposits of the older periods. The existence of both autochthonous and allochthonous deposits is recognized, but he asserts that the former have been the prevailing type throughout and that, in every age, the latter have played an insignificant part.

Potonié finds a strong argument for autochthony in the surprising resemblances, chemical and physical, existing between beds of

⁹⁸ H. Potonié, “Die Entstehung der Steinkohle,” *Naturwiss. Wochenschrift*, IV., 1905, pp. 1–12; the latest edition is “Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt,” fünfte Aufl., Berlin, 1910, pp. 225.

brown and black coal on one side and the modern Flachmoor on the other. The laminated structure is frequently present in peat. The vast extent of some beds of comparatively pure coal cannot be paralleled in recent autochthonous deposits, but the latter are of great extent in some regions, whereas no extensive areas of allochthonous carbon deposits are known to exist anywhere. He lays great stress upon the occurrence of sub-surface parts of fossil plants in the soils where they grew, the so-called petrified humus-soils. He emphasizes especially the mode in which the *Stigmara* rhizomas and their appendices penetrate the underclay of coal beds, spreading out and interlacing in such a manner that transport is inconceivable. They must be in place. Equally conclusive are the modes in which roots of *Calamariaceæ* rhizomas occur in the clays. This almost universal underclay was the soil in which were rooted trees introducing the moor-formation.

The occurrence of forest beds in stone- and brown-coal formation is not infrequent. He notes that at White Inch near Glasgow, Scotland, and that near Senftenberg. Sometimes the profile is shown in the roof; sometimes there are successive forests embedded as at Senftenberg, where erect stumps are associated with prostrate trunks. These are conditions familiar to students of modern swamps. The mode in which the *Stigmara* have developed indicates, in some localities, even the prevailing direction of the wind at the time the trees grew. The growth of reeds in banks and the parallel arrangement of their roots are the same in Mesozoic, Cenozoic and recent deposits.

Potonié carefully distinguishes the features of autochthonous deposits as contrasted with those of allochthonous origin, elaborating the discussion given in the paper just cited. He states that *Stigmara* is not rare in the Commentry basin and that his search there for that plant was rewarded abundantly. He discovered a fine autochthonous stump, with spreading stigmarian rhizomas, still retaining the delicate appendices, the whole occupying a space of 6 meters diameter. He found there also a fern tree, almost completely preserved and with a frond attached to the stem. He concludes that the condition must have been that of great quiet to permit so nearly complete preservation.

Potonié's description of secondary-allochthonous formations, due to erosion and transport of materials from beds already existing, will find place in another connection, as will also his arguments drawn from the testimony of the fossil plants, respecting which his authority is unquestioned.

Ochsenius⁹⁹ published many noteworthy papers but that of 1896 is especially important in this connection. The author recognizes the force of the objection to allochthony—that, as running water carries organic and inorganic materials together, the deposit should be an indiscriminate mass of both kinds but his recent study of coal beds in the Lahn country has convinced him that phenomena observed in the Frische Haff present a true explanation and destroy the force of the objection. The history of the Frische Haff is complete since 1510.¹⁰⁰

The Vistula, a stream laden with everything that can be drawn from a rich lowland province, gives off an arm at Peickel, the Nogat, which flows northeast to the long narrow Frische Haff, separated from the Gulf of Dantzic by the Frisch Nehrung or lowland, and communicating with the gulf by the Pillauer Tiefs at its northern end. For convenience of discussion, he confines his attention to the Nogat, ignoring the old Vistula and the rivers which enter from the east.

Under the supposed conditions, the sea having control and the Haff being filled with salt water, a marine bed is deposited on the floor. Such beds occur locally at the bottom and higher up in the series of coal deposits. Phase 1 of coal formation is brought about through sanding up of Pillauer Tiefs by wave action, and the consequent conversion of the Haff into a fresh-water basin by influx from the Nogat. The débris brought down by that river, an indiscriminate mass of organic and inorganic material, will be deposited on the bottom. If now the sea cut a shallow passage through the lowland, floating stems and twigs would form a "rake" at the head of the

⁹⁹ C. Ochsenius, "Die Bildung der Kohlenflötze," Verhandlungen, II., Erste Hälfte, pp. 224-230.

¹⁰⁰ The Frische Haff is a great sound on the border of the Gulf of Dantzic, about 60 miles long by 5 to 7 miles wide. It may be compared as to superficial area and position to Lake Ponchartrain on the Mississippi delta.

passage. If the water-surface of inflowing stream be lowered, a "barricade" of wood would accumulate in curves and narrows of the Nogat, to become compacted in time—a familiar phenomenon in this day. This "barricade" would prevent passage of large wood and only fine material, "Spulgut" would go over to be deposited as a layer in the coal basin, *i. e.*, the Haff. Brushwood would be caught by the "rake" beyond. Thus a bituminous shale with plant impressions and paper-like laminæ of bright coal would accumulate.

Phase 2 comes with moderate height of the water. Now there goes with the "Spulgut" also the "Sperrgut," stems, rooted stumps, branches and the rest, which the Vistula pushes over into the Nogat; but the "rake" does not permit its escape to the sea, it circles round in the basin, finally sinks and forms pure coal. So much of the mud as does not pass through the "rake" will accumulate on the borders or be mingled with the coal magma, as clay is in the globigerina ooze; or it may form bands in coal beds. Repeated sinkings of waterlevel in the feeding stream, the Nogat in this case, would give a clay shale like the floor as roof, the roof of the coal. No sand or gravel could pass the "barricade" but it would be heaped up there. Phase 3 comes with a high flood, which overthrows the "barricade" and pushes all into the coal basin. The sand and gravel form sandstones and conglomerates as roof of coal beds and formation of coal ceases. The woody portions become at most only isolated stems buried in the "Rollgut"; by repeated pressure they may perhaps be pushed into an oblique position. If the "rake" be torn away, the seawater again enters the basin and lays down a marine bed.

This is the characteristic succession in coal bed formation. All depends on the condition of the water-level. Changes in that cause alternation of clay, shale, coal and psammite, and effect the sharp mechanical separation of those substances by the easily explained formation of "Rakes" and "Barricades." The elevation of important mountain ranges in Carboniferous and Tertiary times afforded abundant material for widespread lowlands, approximating sea-level. These advanced seaward and their luxuriant forest growth yielded material for the stone-and brown coals. Networks of rivers must have cut through the lowlands and must have deposited their loads

in huge depressions. It is clear that many channels fed the coal basin, but all worked after the same fashion. The process throughout was that which Ochsenius terms "Barrenwirkungen" or barricade action.

The memoir discusses many details, rock fragments in coal, stumps filled with sandstone, the occurrence of gypsum, the presence of land shells, all of which are explained very readily by the theory. The conditions at Senftenberg, described by Potonié, are clearly due to this barricade-action.

The numerous coal beds of the Carboniferous were deposited quietly, but they are rarely more than 15 meters thick; whereas the brown coal beds are comparatively few in number, show irregular deposit and at times attain a thickness of 50 meters. The explanation is simple. The soft plants of the Carboniferous had, at most, a diameter of one meter and a height of 40 meters, so that they floated easily in a few meters of water over the "barricade"; whereas the Tertiary and Quaternary giant trees had a diameter of 10 meters and a height of 170 meters, so that they needed a depth of, say, 15 meters to float them over the "barricade." Clearly a depth of one meter would sink more quickly to some centimeters so as to permit only "Spulgut" to pass than would a depth of 15 meters—whence the more frequent interruption of coal deposit in the Carboniferous and the great constancy of formation in Neozoic time.

Almost all our mighty coal deposits are freshwater formations, which came into existence through the factor of "Barrenwirkungen." Autochthony holds in their formation an exceedingly limited place in comparison with that of allochthony.

Schmitz¹⁰¹ has contributed a series of important papers to the literature of the subject.

In 1894, he regarded the *in situ* doctrine as merely a hypothesis. The presence of transported pebbles in the coal itself rather favors the doctrine that the coal is composed of transported materials.

¹⁰¹ G. Schmitz, "A propos des cailloux roulés du houiller," *Ann. Soc. Geol. de Belgique*, XXI., 1894, pp. lxxi-lxxv; "La signification géogénique des Stigmaria au mur des couches d'houille," *Ann. Soc. Sient. de Bruxelles*, XXI., 1897, 6 pp.; "Formation sur place de la houille," *Rev. des. Quest. Scientifiques*, Avril, 1906, 35 pp., 9 pl.

These pebbles, he had discovered, are much more numerous than had been supposed. They are covered with a carbonaceous patine and are found mostly in the lower portion of the beds; he never saw any in the upper portions. The patine suggests that the pebbles may have made a long journey in fermenting pulp, and he thinks that their presence with this coating is confirmatory of Renault's opinions respecting the conditions of deposition of materials composing the coal. At the same time, the "French theory" of the origin of coal, though probable for the ensemble of the coal formation, does not explain the underclay. As for Belgium, the special, the constant facies of the mur is evidence of formation in place. The convincing fact is the presence of *Stigmara* in the mur with interlacing of the rootlets. *Stigmara* remains in the roof are fragmentary.

In 1897, Schmitz reviewed Potonié's paper on Autochthonie; he recognizes that the mur is autochthonous but is not satisfied that that necessarily involves the conclusion that the coal itself is autochthonous also. A mur without coal is evidence of erosion, that its vegetable cover has been washed away. If there be coal without mur, it is allochthonous. A thick bed may be autochthonous below and allochthonous above. While recognizing the valency of many of the arguments presented by Potonié, he is not convinced that they are final.

In 1906, he reviewed the whole subject. His own position in 1896 was that of uncertainty between the old doctrine of autochthony and the new forms of allochthony presented by Fayol and Grand' Eury. Many phenomena observed in the Belgian basins seemed to support Fayol's hypothesis, but the mur, with *Stigmara*, clearly *in loco natali*, is a fact which cannot be ignored. Autochthony found its chief support in conditions observed in recent swamps, but the knowledge of those was too imperfect to make the argument wholly satisfactory; so that Schmitz, at that time, was inclined to hold an intermediate position and to think that both doctrines might be true.

But Potonié's later publication,¹⁰² based on the study of swamps in a great area, goes far toward removing objections. Schmitz summarizes the processes described as occurring in the formation of

¹⁰² "Die Entstehung der Steinkohle."

Sapropel; the gradations from peat to coal; and asserts that all point toward autochthony. He antagonizes conclusions drawn from the presence of vegetable matter in material obtained by deep-sea dredging in the Gulf of Mexico, for that is mingled with ooze and proves nothing for transport. He maintains that vegetable pulp cannot be transported far without notable loss and he urges that black waters from swamps soon lose their color through oxidation, as appears from conditions in the Congo, Rio Negro and other rivers. De Lapparent has protested against the "fascination of present causes" and Schmitz admits willingly that it is an error to seek in the present an absolute representative of the past; but he asserts that it is equally an error to disregard the present in the study of the past.

Schmitz presents an elaborate argument. He traces the formation of Sapropel in an arm of the sea, the encroachment of vegetation, the formation of a bog covered by trees—the *tourbière boisée*, the loss of moisture and the destruction of the forest, the formation of the moss bog with *Sphagnum*, *Scheuchzeria*, etc.—the *tourbière bombée* or hochmoor, which may continue to rise until it reach the heath stage—that of final decrepitude. He shows how this normal development is often interrupted, that a newer stage may return to an older stage or may originate without existence of previous stages.

The wooded bogs are modern representatives of the Carboniferous type. They show conditions observed in the coal beds; peaty maceration disintegrates the most resistant plants so that one rarely recognizes the parts. The mode of growth in bog plants resembles that of the coal plants; the root is radial not tap. He describes an extensive bog in Hanover, in which the peat had been burned, leaving exposed great tree-trunks, the luxurious crown existing when the bog was wooded; if that bog had been covered with sediment during the life of those trees, there would have been a legion of autochthonous tree-trunks.

The immensity of the great coal areas, to be compared with the immensity of modern bogs, must not be disregarded. One cannot think of the great Westphalian-Belgian-English basin as a mere lagoon to be filled by rivers; and Schmitz asks how vast must have

been the low country to yield humic material for the coal beds of that basin. He thinks that to accept the land conditions necessary would require too great draft on one's credulity. But the case is wholly different with the peat bog theory.

Schmitz concludes that the coal systems consist of allochthonous rocks and autochthonous coal beds. The underclay is not a special sediment; it is a sediment modified by the establishment of vegetation. There must have been some allochthonous deposits of carbonaceous matter, but they were merely local. The accumulation as a whole was autochthonous, after the manner of the forested swamps.

Sterzel¹⁰³ thinks that very probably no theory of formation is of universal application, the conditions being unlike in different regions, even in different parts of the same region. In studying the Zwickau region area, he became convinced that plants embedded in shales accompanying the coal are not in their original place, for they are broken, they are in different stages of decomposition, their remains are mostly parallel to the stratification, and they show distinct evidence of sorting due to currents of water. Plants *in situ* occur only locally.

Some features favor belief in the autochthony of coal; the narrow variations in thickness of important beds within great areas; the small proportion of ash in many beds; the localization of *Stigmaria* in the Liegenden; the occurrence of erect stems in the Hangenden. But there are others equally favoring allochthony; the distinct lamination of the coal; the mineral matter, often forming a considerable part of the bed, is mostly clay, the same with that of the roof and floor, and it tells of quiet deposition; *Stigmaria* occurs abundantly in the roof of coal beds; erect stems are of exceptional occurrence.

The greater number of phenomena favor allochthonous origin of the Zwickau coal beds. They were deposited in a lake basin surrounded by forested swamps. The gently inflowing waters carried little mineral matter and the plant material accumulated long time on the bottom, where it was converted slowly into coal. When the

¹⁰³ T. Sterzel, "Palaeontologische Charakter der Steinkohlenformation und des Rothliegenden von Zwickau in den Erläuterung zur geologischen Spezialkarte," Section Zwickau, 1891, pp. 87-142; "Mittheil. aus d. Naturw. Sammlung d. Stadt-Chemnitz," 1903, 22 pp.

water-courses swelled, a great quantity of material, inorganic detritus, was brought down to form the intervening bed, on which, when quiet was restored, the plant material was deposited anew. Periodical changes, slight crustal movements, variation in fall of rivers, lead to deposit of a great mass of rock over the coal bed; the thickness of this intervening rock depending on the extent and continuance of those changes. When quiet returns, the forested swamp again expands. Many localities with particular species of plants had been destroyed wholly and those forms do not reappear in later beds—an explanation of the irregular occurrence of plant-forms in the series.

The lake was comparatively deep, for the Zwickau measures are about 400 meters thick. By accepting this hypothesis of a lake, one finds explanation also of the origin of the great salt-content characterizing the Zwickau deposits—in 1854, 400,000 kilos of sodium chloride and 15,000 kilos of calcium chloride were obtained from mine waters of the Tufen Planitzer beds.

In 1903, Sterzel qualified a statement made on p. 90 of the preceding paper, which refers to the value of erect stems as evidence. The only stems of that sort, observed by him, were "Sargdeckel," the "coal-pipes" of English miners. One *Sigillaria* stump, examined by him, was completely cut off at the base, with no trace of *Stigmara*. It had been torn from its place by running water, robbed of basal branches and then deposited in the roof of the bed, where its softened bottom was flattened under pressure. He notes that the overlying rock is sharply defined, that there is no passage of plants from the coal, such as would be the case if the place of plant-growth were flooded by masses of rock material.

Lemiere¹⁰⁴ presented a memoir to the Geological Congress of 1900, which discussed the conversion of vegetable matter into coal. In 1904, he returned to the subject and considered in addition the manner in which coal beds accumulated. The discussion is based largely on the assumption and conclusions of Fayol that the coal

¹⁰⁴ L. Lemiere, "Sur la transformation des végétaux en combustible fossiles," *C. R. Congrès Géol. Intern.*, Paris, 1901, pp. 500-520; "Formation et recherches comparées des divers combustibles fossiles," *Bull. Soc. de l'Ind. Min.*, 4^{me} ser., IV., V. Published separately, 1905. Citations from pp. 70-142.

beds were formed of transported vegetable matter deposited in basins of deep water. In this later memoir, he discusses the laws governing deposition of inorganic materials of varying density and shape, on lake bottoms in tranquil water, on beds of streams and on shores exposed to the action of waves. This completed, he applies the ascertained principles to explain the formation of coal deposits.

The basins in which those deposits were laid down were ordinarily gaping faults, very long except where divided transversely by uplifted granite, and, in many cases, the fault is still apparent. Streams began to flow into the basins at once. Where the fault valley was divided transversely by uplifted granite, lake basins were formed like Commentry, Montvicq, etc., in which the beds are irregular. At other times the fracture valley retained its length and was wide enough to be a strait or estuary, common to several rivers and bordering on seas extensive enough to be affected by tides and waves. Respecting the latter he makes the frank remark: "It is hardly possible to admit that the areas of coal deposit were in direct communication with the high sea, because high-level floods are little compatible with free access of this [the ocean]; now, the floods are a condition, *sine qua non*, of vegetable contributions; it is necessary, then, to admit that the areas of deposition were lagoons, sheltered from the ordinary tides, fronted by vast low plains, themselves above the tides and furnishing few coarse elements to the river load."

Other basins retaining their length, were less affected by marine conditions, possibly because of the narrowness or because of variations in level. Of such is the great syncline extending from Moulins to Decazeville. The deposits are lacustrine. The form of the depression affects the speed of currents and therefore the type of deposits; if broad, the rivers from different points form deltas, but if narrow, the speed along the middle is such as to sweep away such deposits. The contrasting conditions are shown by the Saint-Etienne and Rive-de-Gier divisions of the Loire coal basin.

The vegetable matter, to form coal beds, was brought in mostly during floods; some of it remained afloat; some was held in suspension; while some, which had undergone thorough maceration,

sank immediately. But all alike were deposited at last on the soaked talus of the delta. The lake basin, in which the deposition was made, is conceived to have been quite deep, for Lemièr's diagram shows curves to a depth of 350 meters and the last is still at considerable distance from the bottom; it is supposed also to be large in comparison with the breadth of the tributary streams. The important source of plant material is the space along the streams between the average low water line and that reached by high floods; but the still higher portions of the drainage area, being exposed to rain and wind, would contribute.

During a long period of low water, little aside from inorganic matter would be carried to the basin; but when that was followed by a period of heavy rains, the forested area was invaded, the vegetable contributions were increased, while inorganic contributions were decreased. The forest soil was covered with humus, which had been accumulating without cessation. The soil, thus covered, became increasingly unfavorable to vegetation, whose roots as Grand' Eury says, hate to penetrate it deeply. Lemièr thinks this a "peremptory argument against formation *sur place* of coal beds formed by aerial plants very different from those which have formed peat bogs. That the forest might continue and might renew itself after destruction, it was necessary that the soil be cleared away at intervals by winds, rains and especially by floods."

The humus, already macerated and denser than living plants, was swept off first; afterwards, the living plants would be uprooted and broken. The macerated humus, being denser, was deposited on the convex surfaces of the delta, while the living plants had to become watersoaked before sinking, so that they were superimposed upon the other plant material. They would come to rest more abundantly in the bays between deltas, so that one should find more of volatile matters in coal laid down within the bays than in that deposited on the delta slopes, along the axes of the currents. The volatile should increase as one departs from those axes but it should decrease with the depth at which the vegetable matter was deposited.

Floating islands are possible, since a flood might tear off bodily part of a forest, which, carried down, might float for a while and

then sink to give the appearance of growth *in situ*. If the storm continue long enough, it would wash off the soil itself, which would become an intercalation in the bed. If the flood return, attaining a higher stage than before, another area of forest region would be torn off to form a new bench of coal, possibly directly on the other. When the flood subsides, the superficial currents would find only inorganic materials on which to act, and the first deposit would be mud to form the roof of the coal bed, after which would follow some sandstone and conglomerate. Between floods the vegetation is restored and the area is increased by encroachment on the lake. During this long interval, the flora might be changed.

Lemière is convinced that, by his hypothesis, he has succeeded in explaining converging beds, parallel formations and floating islets. All are allochthonous; aerial plants have formed no autochthonous beds, for no erect stem has been found in the coal; in fact, the plants could not thrive in a humus not nitrified. Peat cannot become coal, as its tannic acid checks the process of conversion. He applies his doctrine with great ingenuity to several basins in France and finds it confirmed in all.

Lemière¹⁰⁸ has published several papers in more recent years and he presented a résumé of his opinions in 1910. In that he expresses surprise that in recent congresses the dominant opinion was that coal beds are ancient wooded-bogs buried by successive subsidences, because this opinion involves the supposition that the coal beds were not formed in the same way as the sterile beds which enclose and, at times, penetrate them. This opinion is based upon palaeobotanical evidence, which is often untrustworthy, providing two-edged weapons, available equally for defenders of each theory. It is necessary to discover some criterion which will be conclusive. In an earlier paper, he had demonstrated finally in geometric form that the peat bog theory leads to arrangement of beds unknown in nature. In this he proposes to restudy the conditions after the same method, avoiding palæontological discoveries, and availing himself of discoveries which have the character of certitude. He describes three types of structure observed in areas of the coal formation.

¹⁰⁸ L. Lemiere, "Résumé des théories sur la formation de la houille," *Bull. C. R. mensuels. Soc. Ind. Min.*, Sept., 1910, separate, 19 pp.

The first type is that of the Hainaut coal basin in Belgium, a small area, 15 kilometers wide and separated from the Campine basin at the northwest by 60 kilometers of older rocks, while on the southeast it is bounded by a fault. The fossils show that, at times, this basin communicated with the sea. The deposits are thin at the north, where the beds have remained unaffected by subsequent disturbance; but they thicken to 3 kilometers toward the southerly border of the basin, where the disturbance increases as the fault is approached, the downthrow having caused close folding. The hinge of movement was near the southeast bounding fault. If the peat bogs were formed at the unvarying sea-level, the first of them should have had, when the basin was filled, an inclination of 25 cm. per meter and the last should be almost at sea-level, while the intermediary beds should converge toward the shore line at the northwest. The conditions being absent, it is evident from this mathematical demonstration that the coal beds are not buried peat bogs. The warning against the dangers of dependence on palaeontology is repeated, and the necessity for the warning is proved by the discovery of the Bernissart iguanodons in rocks other than those to which the animals belonged, as well as by the possibility that some day remains of fossil man may be discovered under a landslide from a chalk cliff.

The second illustration is that of an area, increasing in extent as it deepens. There, convergence of the beds toward the hinge of movement would not be a criterion. The upper beds should be of greater extent than the lower. This is to explain conditions existing in the Appalachian basin, where one thick coal bed, the Pittsburgh, has an area equivalent to not less than 400 kilometers square. It is difficult to understand how materials from the anticlinal borders could reach the central parts of such a synclinal to give parallel beds there. In the central parts of the basin are great masses of red shale and beds of limestone and the coal beds are not rigorously parallel. He is inclined to think that the materials within the central parts are due to precipitation (from solution) without mechanical transportation from the borders. One cannot assert

positively that in this area peat bogs are excluded from consideration.¹⁰⁶

The third illustration is from the basin of Vendée, which is an isoclinal formation in an isoclinal valley, bounded on one side by a fault. The reference to this area is brief. Lemière states that the phenomena of the *faisceaux* at the north and the dips in the basin suggest, *a priori*, that here one has a case of peat bog formation. But he plots the conditions in a diagram and states that, as shown thus, they are evidently due to influence of the fault.

He concludes that the French coals as well as those of the Franco-Belgian basin are not old peat bogs but are of alluvial origin and that the same conclusion is probable for the coal beds of North America. These conclusions do not proscribe the theory of peat bogs; on the contrary they appropriate those conditions and their results. All that is insisted on is that, at present, we can find no trace of successive deepening of feeble amplitude and repeated for each bed; but there are evidences of many subsidences, important or at distant intervals, corresponding to the *faisceaux* of beds.

Lemière, feeling himself no longer in danger of being paralyzed by the question, Is coal formed *in situ* or as alluvium?, proceeds to show wherein his doctrine differs from other forms of the transport theory. As the distinction depends in great measure on his conception of the mode in which vegetable matter was converted into coal, the details have no place here.

This extended reference to Lemière's publications is justified by the fact that he has presented the characteristic of the transport theory more fully than most of his predecessors and has attempted to explain all the conditions as far as they are known to him.

Stainier,¹⁰⁷ whose numerous contributions will find consideration in another connection, believes that formation of coal beds is essentially a geological problem and he maintains that geologists have been negligent in that they have left the discussion too long to the palæobotanists. Fayol and Grand' Eury, by studying the matter

¹⁰⁶ The diagram, illustrating the structure in this second case, shows a bounding fault on one side, such as limits the little basins in France.

¹⁰⁷ X. Stainier, "De la formation des gisements houillers," *Bull. Soc. Belge de Géol.*, XX., 1906, p. V., pp. 112-114.

geologically, have succeeded in solving the problem for the basins of central France. He hopes by following their methods to solve the problem in the great basins of northwestern Europe.

If one study not the coal beds alone but also the whole series of deposits in those coal basins, he finds that their strata differ in no wise from those of terranes, whose marine origin is recognized by all. No feature of coal beds suggests a different origin for them. On the contrary, when one endeavors to explain the formation of coal beds by the *in situ* doctrine, he find himself, at each step, contradicting the best established laws of geology. These contradictions, naturally not apparent to the botanists, ought long ago to have spurred geologists to make investigations for themselves. They have led Stainier to believe that coal beds, like the encasing rocks, are of purely sedimentary origin.

For him, the coal plants grew on continents, bordering great depressions, into which meteoric agencies carried the vegetable débris along with materials torn from the land by erosion. These materials, vegetable and inorganic, were mingled intimately while the water was in agitation; but in proportion as the condition of calm was re-established, they were thrown down to the bottom in a well defined order, determined by density of the materials. In cases where the succession is complete, there was formed, first, a bed of sand, ultimately becoming a bed of sandstone; then a peculiar, irregular rock, which constitutes the mur and contains the denser parts of the vegetables, *i. e.*, the sub-surface organs; then the remaining portion of the vegetable débris was deposited to form a coal bed; and finally, the impalpable elements, fine clays, reached the bottom, giving tender fine shales, the roof of the coal bed.

The reasoning on which the conclusions are based is to be given in a memoir not yet published.

Ashley¹⁰⁸ has offered suggestions which are not without interest here. Adopting the doctrine of autochthony, he ignores in his calculations the cannels as well as other merely local deposits, which are allochthonous and therefore outside of the discussion. He finds

¹⁰⁸ G. H. Ashley, "Maximum Deposition of Coal in the Appalachian Coal Field," *Econ. Geology*, I., 1906, pp. 788-793; II., pp. 34-47; "Significant Time Breaks in Coal Deposition," *Science*, N. S., XXX., 1909, p. 129.

that under exceedingly favorable conditions a peat bog has gained one foot of thickness in five years but that in one case this increase appeared to be only one foot in two hundred years. With the conditions normal, the rate of increase seems to be not far from one foot in ten years. Reasoning from the approximately ascertained ratio of volume of peat and the resulting coal, he conceives that 300 years would be required for the formation of one foot of coal, thus giving a period of about 4,000 years for accumulation of the Pittsburgh coal bed in western Maryland. The minimum period to be assigned for formation of the 300 feet of coal in the Appalachian basin is not far from 100,000 years.

In his later paper, seeking to ascertain whether or not a coal bed may be utilized as a time measure, he indicates some complexities of the problem, one of which is important. A coal bed, 18 inches thick at one locality may be 15 feet at another, the latter thickness requiring for accumulation 4,000 years more than the other. As the rocks accompanying the thinner bed show no compensating differences, the 18 inches is all that was formed while the 15 feet was accumulating elsewhere. There was either slow growth or a time-break, that is a period of no deposition, before or after deposition of the thin bed.

"Smooth-partings" are evidences of time-breaks and represent locally nonconformity between the under- and the overlying beds: a "smooth-parting" at one place may be equivalent to 40 feet of shale at another; an inch or two of cannel may have similar equivalence. Slow growth and temporary cessation of deposition are important elements of the problem.

Dannenberg¹⁰⁹ finds strong arguments in favor of autochthonous formation in the vast extent of some coal areas, the presence of the tenderest plant-parts in coal inclusions, the abundant occurrence of roots directly under the coal, and the identity of coal-forming plant species with those found in the enclosing shale rocks. Not all localities show these features with equal clearness, for in some cases there are variations along dip and strike like those in delta deposits,

¹⁰⁹ A. Dannenberg, "Geologie der Steinkohlenlager, Berlin, 1909; Erster Teil, 197 pp. The citations are from pp. 18-27.

such as appear in the basins of central France, which Fayol has proved to be allochthonous.

The deposits must have been made in shallow water; Grand'Eury has shown that the autochthonous flora of the Loire basin could not have grown in water more than 10 to 15 meters deep. There must have been a special combination of circumstances, since the deposits, in spite of the shallowness of the water, have in some basins a thickness of some thousands of meters. This can be understood if one accept a constant though variable subsidence throughout the period of deposition. A certain instability of coast line in paralic basins is proved by repeated inroads of the sea. If the sediments be laid down less rapidly than the surface sinks, marine conditions prevail. Periods of rest, possibly of some elevation, would be favorable to development of swamp vegetation, which, when subsidence began again, would be buried under muddy and sandy deposits, until a new swampy area was produced, on which vegetation began *de novo*. These movements can be followed with great clearness in the Saarbruck and Loire basins.

Similar movements in the period of man can be recognized along many coasts. Dannenberg regards the Tertiary and Quaternary history of the Netherlands as especially instructive. This he gives in detail, showing that there have been successive advances and retreats of the shore line, so that the section of Tertiary and Quaternary beds consists of sandstones, conglomerates, shales, marine beds and peat deposits, wholly similar to the succession observed in the Coal Measures. The filled river valleys observed in the Coal Measures, have their counterparts in these newer deposits. And it must not be forgotten that, in the Carboniferous time, great orogenic movements occurred, so that there was abundant material for filling the basins.

Stevenson,¹¹⁰ after studying the area, found himself unable to accept Fayol's conclusions respecting the mode in which the coal beds were formed in the basin of Commentry. He agreed fully with Fayol as to the process by which the inorganic deposits were laid

¹¹⁰ J. J. Stevenson, "The Coal Basin of Commentry in Central France," *Ann. N. Y. Acad. Sci.*, XIX., 1910, pp. 161-204, 6 pl.; "The Coal Basin of Decazeville, France," the same, XX., 1911, pp. 243-294, 2 pl.

down, seeing there the conditions of delta formation as long recognized by geologists in American coal fields; but he could discover no reason for supposing that the coal beds were formed of plant materials washed in from the drainage area. That hypothesis, as presented for this region, seems to be self-contradictory. The supposed surface conditions at the beginning of the history were such that dense vegetable cover seems in the last degree improbable; but the vegetation required by the hypothesis was so dense, that it would have been its own protection against any but a long-continued series of the most terrific cloud-bursts; in case of such a débâcle, only a small part of the vegetable matter could be deposited as a coal bed, for the trees, supposed to have composed one half of the whole vegetation, would be loaded by material around their roots, would be snags in the mass of detritus and would be buried in the sands; even the twigs and underbrush would be entangled in the mass, for there could be no sorting action in the short course of the little torrent and all would be dropped when the flood's velocity was checked on the comparatively broad delta surface, supposed to exist when formation of the Grande Couche began. Only the finest material, mineral, or vegetable, could find its way to the bottom of the basin—yet it is certain that trees make up a very considerable part of the Grande Couche. The objections presented by this writer will be considered in another connection. He thinks that the structure of the Grande Couche shows that its vegetation accumulated *in situ* and that there is no evidence to favor the suggestion that Lake Commeny was a deep water basin at the time when coal accumulation began.

Study of the Decazeville basin led him to similar conclusions respecting that area. The conditions there are very different from those in the Commeny basin, so different that any doctrine of transport formulated to account for the conditions at Commeny could not be applicable at Decazeville.

Study of investigations by v. Gümbel and Potonié led Gothan¹¹¹ to study the coal area near Fünfkirchen. The economic importance of the Liassic coals within that area had been known for more than

¹¹¹ W. Gothan, "Untersuchungen über die Entstehung der Lias-Steinkohlenflötze bei Fünfkirchen (Pecs, Ungarn)," *Sitzungsber. d. k. preuss. Akad.*, VIII., 1910, pp. 129-143.

100 years and the relations of the beds had been described by several geologists; but nothing was known which showed the mode in which the coals had accumulated. The section contains about 100 coal beds, of which fully 25 attain workable thickness in much of the area. Gothan had already discovered underclays with roots associated with Mesozoic coal beds on the Yorkshire coast of England, and it seemed probable that search for similar clays at Fünfkirchen would be successful.

He was not disappointed, though he found the difficulties in the way of study greater than anticipated.

Under the coal bed, no. 7, there is a well-marked underclay with irregular branching coaly markings, varying in diameter and in every respect resembling roots; and, at one locality, a rhizoma with its rootlets was complete, enabling him to determine the relations of the other forms. "Through such horizontal rhizomas, the analogy of this Mesozoic underclay with the Carboniferous *Stigmaria*-beds and the recent or sub-recent reed-beds is the more marked." A four-inch layer of carbonaceous shale lies between the underclay and the coal, but one cannot trace the roots in it; they cannot be distinguished in the dark material, which is so crossed by cleavage planes that none but irregular angular fragments can be obtained. The planes do not coincide with the direction of the rootlets.

Roots are seldom observed in the freshly exposed rock within the mines, but they are distinct enough where the rock is somewhat weathered. Gothan exposed the outcrop for several meters at different horizons and in the course of a day's excursion, he found well-marked underclays, with roots, associated with 8 coal beds. The analogy with Tertiary and Quaternary underclays is complete. His conclusions are that the underclay, associated in more than a dozen instances, with the Fünfkirchen coal beds, shows that these are, for the most part, of autochthonous origin, as are, predominantly, the younger and older humus deposits of the present time as well as those of the Tertiary and Palæozoic. The failure to secure proof of this origin for all the Fünfkirchen beds is due merely to the unfavorable conditions to which reference has been made. In a footnote he notes his discovery of typical underclay, with roots, just below a Wealden coal bed in a neighboring district.

THE FORMATION OF COAL BEDS. II.*

By JOHN J. STEVENSON.

SOME ELEMENTARY PROBLEMS.

(Read November 3, 1911.)

It is necessary, first of all, to consider some matters to which reference is made by every one who has endeavored to explain the formation of coal beds. Too many seem to have been content with acceptance of current statements respecting the apparently commonplace phenomena and too few have thought essential a careful study of work done in recent years. The indefinite and often contradictory assertions contained in discussions, published within the last decade, compelled the writer to study the available literature and, as far as possible, to make examination of the phenomena in place. This study has led him to reject some of his cherished beliefs while it has confirmed others. At the same time, it has increased his respect for the problem, which he has undertaken to solve. The topics to be considered in this portion of the work are:

The effect of floods upon a cover of vegetation,

The phenomena of peat deposits,

The buried forests.

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Each of these topics will be considered only in its relation to the main problem.

THE EFFECT OF FLOODS UPON A COVER OF VEGETATION.

A torrent dashing through a narrow gorge is the poet's symbol of resistless force; a great river in flood, bearing on its surface houses, trees and other floating materials in prodigious quantity, seems possessed of almost illimitable power for destruction. These conditions, so familiar to all, have led to the conception that, in the eroding and transporting power of streams in flood, one can find explanation for the origin not only of sandstone and other inorganic deposits but also for that of coal and lignite beds interstratified with them. So much importance has been assigned to this explanation by several authors, that the phenomena must be considered in detail.

The Work of Torrents.—The torrent in full flood is an interesting spectacle but its importance in this connection is confined chiefly to its bearing on the origin of inorganic sediments.

Long ago De Luc¹ described deposits made by torrents as resembling a much flattened loaf of sugar and he employed the term "cone" to distinguish them from the talus at foot of cliffs. When a stream ceases the cutting down of its bed, the formation of a cone ends and vegetation takes possession of the surface, even of steep slopes alongside of the stream. Eventually the surface is covered with a thin coat of soil and men settle upon it. Such a cone was seen by De Luc on the right bank of the river Arc, en route from Mount Cenis into Italy. It extends from Aigue-belle to Saint-Jean de Maurienne and the line around its base is nearly three miles. It is high against the rocky wall and the surface is comparatively steep. Its history is the same with that of many others. The stream cuts a channel in the cone; occasionally, during a great flood, the banks are overflowed, but the injury is not enough to drive away the inhabitants. A fall from the walls of the gorge forms a talus against which the stream flows; water finds its way through the sands and

¹ J. A. DeLuc, "Lettres physiques et morales sur l'histoire de la terre et de l'homme," Vol. II., 1780, pp. 67-68.

renders the mass almost jelly-like. A winter of heavy snows, followed by an unusually warm spring, leads to abrupt swelling of the water and the soft mass is swept out over the surface of the cone, flowing like a flood of lava. Such were the conditions here. A village, la Chapelle, had been built; in 1752, the torrent washed out a vast mass of rock and débris, which covered everything to a depth of 15 to 20 feet, completely burying the hamlet.

In a broad valley, the effects of the torrent's work are confined to the cone, but conditions are different where the valley is narrow. A few years prior to the disaster at la Chapelle, another cone was formed in the Arc valley between Saint-Andre and Saint-Michel. The river was dammed and a lake was the result. The inhabitants of a drowned hamlet endeavored to make a canal through the dam, but the great fragments foiled them and the river was left to make its own canal. De Luc visited the locality several times. When he last saw it, the river had filled the lake with débris, through which it flowed gently, while above and below it foamed amid masses of rock. De Luc notes with some interest that on the other side of the valley, opposite la Chapelle, a torrent was still at work, building its cone. Each spring saw the surface covered by a flood, bringing down new material. Yet the trees, which had gained place and had sent their roots down amid the rock-fragments, maintained themselves against the rushing waters, laden with rocks and débris, and inhabitants of the region gathered fagots there.

Similar phenomena are familiar to all students of mountainous areas. Dejection cones, some of them enormous, are numerous along the Rhone from Viège to Martigny. The flood additions are distinct, several of the cones being deposited by streams with fall of more than 250 feet per mile. Except where new channels had been cut, the trees growing on the surface of the cones are apparently uninjured, though in some cases they have been bent by blocks of rock, whose advance they had checked. The valley of the Adige between Botzen and Rovereto presents many illustrations of similar type; in the mountain areas of the western United States such conditions are merely commonplace.

McGee's² observations in the Sonoran district of Arizona and Mexico are equally instructive, though dealing with a somewhat different type of phenomena. That district is within the arid region and the valleys are sand wastes, with shallow channel ways which are dry during all but, perhaps, five days in each year. The mountains are scarred by barrancas or stream-worn valleys, which end abruptly at the plain. The streams during the greater part of the year are mere threads; but, during thunder gusts or cloudbursts, the old channels are filled and new ones dugged, though the flow may last but a few minutes or at the most a few hours. The stream gathers loosened rock masses in the mountains, hurls them down slopes into the barrancas, dashing them to fragments and carrying the débris to the edge of the plain. There the coarser materials are dropped, but the finer stuff is transported beyond as a sheetflood until the water disappears by absorption or evaporation. The inclination of the channel ways is not far from 300 feet per mile in the mountains, decreases to 200 feet at the edge of the plain and to 50 feet at the end of the torrential area, several miles away. The flooding of the plain has, in some cases, a width of ten or more miles.

McGee saw one of the floods in 1894. It came abruptly, a mass of water thick with sand, foaming and loaded with twigs and dead leaves. It advanced at first with "racehorse speed" but the velocity diminished quickly owing to evaporation and the flood died out in irregular lobes. The depth was not more than 18 inches on the lower border, where the width of the muddy flood was about half a mile. The noteworthy feature in this connection is that the mass of slime, moving with so great speed, had no injurious effect upon the clumps of mesquite bushes, scattered here and there over the slope. When the flowing mud reached those clumps, its speed was checked momentarily; its course was diverted and it moved alongside at twice to thrice the ordinary rate. After the flood was over, the most striking observable effect was the accumulation of twigs and branches against the clumps of shrubbery and other obstacles.

Russell's notes on the Yahtse river of Alaska, to be considered

²W J McGee, "Sheetflood Erosion," *Bull. Geol. Soc. America*, Vol. VIII., 1897, pp. 87-112.

in another connection, are equally in place here. That river, issuing from the Malaspina glacier as a swift flood, 100 feet wide and 15 to 20 feet deep, has invaded a forest and surrounded the trees with sands and gravel to a depth of many feet. That current, rapid enough to carry a great load of very coarse material, was not strong enough to uproot the trees and evidently it could not break off the trunks until decay was well advanced. Russell's photograph shows the conditions distinctly.

Smyth⁸ has described conditions in the Adirondack mountains of New York, which are of no little importance in this connection and they will be utilized in the sequel, as the character of the region is very like that imagined for some limnic basins in Europe. Many small lakes exist in that region, varying from a few rods to three or four miles in the longer diameter. They are of post-glacial origin and, in many cases, are surrounded by high hills of metamorphic rock, whence streams with rapid fall flow in comparatively narrow valleys. Big Rock lake is typical. It is a mile and a half long, three fourths of a mile wide and is fed by streams which carry much sediment and by their deposits are changing the outline of the lake. The new area is a level marshy meadow, about a foot above the water, covered with a heavy growth of grass and carrying some small balsams and tamaracks. The lakes show every stage from pond to meadow and one of them has been changed throughout into meadow, through which its stream meanders on the way to Big Rock lake, one mile away. After heavy rains, water flows over the meadows to a depth of a foot or more, leaving a sediment of varying thickness; but the torrential streams feeding the lake, though flowing through gorges, whose steep walls are more or less densely timbered, rarely bring down trees or other vegetation.

Torrents carrying no débris do as little injury to vegetation as to the rocks over which they flow. The writer has recognized this many times in the Rocky and other mountain areas of the western United States. Clear creek in Colorado, formed by the union of streams from Gray, Torrey and other high peaks of the Front range,

⁸ C. H. Smyth, "Lake Filling in the Adirondack Region," *Amer. Geologist*, Vol. XI., 1893, pp. 85-90.

is subject to abrupt rise in the early summer, when hot days cause rapid melting of the snow on those peaks. The upper streams pass over hard rocks and among huge masses which choke the channels, so that, below the union, the creek, following a rocky, mostly narrow gorge and with rapid fall, carries even in great flood comparatively little sand or silt. A rise of 10 feet within 3 or 4 hours is of frequent occurrence. The low narrow "bottom," though so often overflowed by rapidly moving water, is grassy and bears some shrubs. In some places, where the canyon widens and the stream, under ordinary conditions, flows less rapidly, one finds petty islands of detritus covered by shrubs, some of them more than 15 feet high. Clearly these plants are torrent-proof, they have maintained their place from birth. Similar conditions were observed on many other streams of like character.

A Cover of Vegetation Protects against Erosion.—Within any given district of moderate size, some streams are turbid while others are limpid even in flood time. The water may be limpid or turbid in different portions of the same stream. As the rainfall is the same throughout there must be local causes for the variation.

The process of erosion begins with the impact of a raindrop; but that impact is ineffective if the drop fall on more or less elastic material. Thus it is that a cover of decayed vegetable matter, a coating of humus, protects a slope against the erosive power of rainfall; it protects existing vegetation from removal and it may enable plants to regain hold on spaces bared by fire or other agents, even though the slope be abrupt.

Ashe⁴ studied an area which has great variety of soils, as the section extends from the Archean to the Quaternary. Soils from partly metamorphosed sandy shales or from mica schist offer little resistance to erosion; in some cases they cannot nourish a sod but each supports its own type of trees. Denuded of forest, the surface is gashed quickly by rains, but when forested it loses little. The accumulation of litter or humus within the Potomac area is small

⁴W. W. Ashe, "Relations of Soils and Forest Cover to Quality and Quantity of Surface Water in the Potomac Basin," *U. S. Geol. Survey, Water Supply and Irrigation Paper*, 192, 1907, pp. 299-335.

because of climatic conditions, but it suffices to protect these soils on all except the steepest slopes. Limestone soils, occupying much of the area, are very apt to "wash" when under cultivation, but where covered with forest even the steepest slopes retain their cover of humus and the run-off water is never turbid. Sandstone soils vary much in resistance, when bared, but where they are protected by a thin cover of humus the waste is insignificant. The water of small streams flowing from forest mountain-sheds is clear and pure. The great resistance offered by humus is apparent from the figures given by Ashe. Pines growing on poor soils, rarely yield more than 2 inches; yet this protects all except the steepest slopes. Chestnut oak and white oak give but 3 inches; they too grow on poor soils, which, when exposed, are torn away rapidly. Other woods give from 5 to 6 inches of litter, which is so absorbent that for several days after a rain one can squeeze water from it as from a sponge. Ashe's observations show that this vegetable litter, in the semi-decomposed condition, is so interwoven that it not only protects the underlying soil but also itself resists removal as does a well-rooted sod. The streams coming from the humus covered area are free from vegetable matter, aside from occasional twigs and, at times, some soluble matters leached from the humus.

The White mountains of New Hampshire illustrate well the incompetence of rainfall to remove living vegetation. The rock in that region is mostly granite and the soil, formed since the glacial period, is very largely humus. The slopes are abrupt and the walls of gorges frequently show more than 50 degrees; but most of the area below timber line has a dense cover of vegetation, largely spruce. Yet rains have always been frequent and many times almost deluge-like. The covering of humus is undisturbed by those rains; even where lumbermen have cut away the forest and left their litter and the humus exposed to the fury of storms, one finds little evidence of removal.

Cloudbursts or extraordinary downpours of rain have occurred many times within this area. C. H. Hitchcock has described the flood in the Flume at Franconia, which washed away the great boulder which had been dropped by the retreating ice and had re-

mained suspended in the Flume. That huge mass has never been found. Yet, aside from a landslide or two, the terrific rainfall left the vegetation on the steep slopes unscarred. In June of 1903, a cloudburst of unusual severity broke on the northern part of the White mountains. The roads were gullied and rendered impassable; bridges, large and small, were swept away throughout the region as the streams were filled beyond the high water mark of spring freshets; sheets of water poured down naked rock surfaces in many portions of the abrupt spaces and landslides of limited extent were produced where the slope was covered with loose material. But this vast flood of water did practically no injury to the forest-covered slopes; even débris left on the mountain side by tree-choppers was almost undisturbed.⁵

But the most noteworthy evidence in this region is found on the areas which have been burned over. When a forest fire destroys the soil near the top of a divide or on a very abrupt slope, the residue is removed quickly by rain and the granite is exposed. But if the organic matter has not been destroyed, the soil resists ordinary rains even on steep slopes. If drenching rains be delayed for a few weeks, the surface gains a cover of fireweed (*Erechtites hieracifolia*) and rain is powerless. This growth is succeeded in the following season by a dense cover of raspberry, fern and other plants, among which a cherry takes root to become the characteristic form in the third season. Birches, maples and poplars are prominent during the next season and within five years the spruces make their appearance. If drenching rains follow quickly after a forest fire, the process of restoration is merely retarded, it is not prevented.

Glenn⁶ studied the problem throughout the southern Appalachians, an area of 400 by 150 miles, and his studies were extended to another area farther north, 200 by 50 miles. The examination was continued westward for a long distance down the Tennessee river, so that the investigation embraced every type from the bold

⁵ Communicated by C. A. Snell of Malden, Mass., who examined the whole area within four days after the disaster occurred.

⁶ L. C. Glenn, "Denudation and Erosion in the Southern Appalachian Region," *U. S. Geol. Survey, Professional Paper*, 72, 1911, pp. 15-18, 23, 24, 59, 93, 96, 99.

mountains, cut by canyon-like gorges, to broad river valleys with wide bottoms in which the streams meander. This study concerns also some matters to be considered hereafter, but they are included here for convenience of reference.

Glenn asserts that, in forested areas, erosion is at its minimum, for the soil is protected by the litter from impact of raindrops. As drops move down the slope, they are checked by the litter or are absorbed by it, and the rainfall moves so slowly through the mass that for hours after rainfall, the cover is full of water. Even such gullies as were seen have their bottoms covered with litter and plants, showing that the erosion, by which they have been produced, is very slow. Streams flowing from the forested regions rise gradually during heavy rains and fall to normal more gradually, because the litter retards flow. Such streams, even when highest, are, as a rule, but slightly discolored and that discoloration is caused in great part by macerated fragments of leaves and decaying plants, for they carry little mineral matter in suspension. Some of them remain wholly clear even when swollen to far beyond their normal stage. But removal of the forest brings about an abrupt change. The protective efficiency of even a root-matted soil is evident, for when a tree is uprooted or a road is cut, so as to break the continuity, erosion begins at once. The contrast between forested and denuded areas is so striking that no argument is needed. Grass-covered slopes may be destroyed by breaks made when a cow crosses them after prolonged rainfall, but erosion can be checked by covering the surface with litter, held in place by brush; weeds and bushes spring up quickly. The writer adds his testimony in confirmation of these observations by Glenn, for he has seen many thousands of acres of cleared land, which had been abandoned after a few years of cultivation and which now are covered by a dense growth of hard wood—and this on the steep slopes of the Virginian Appalachians.

Glenn's volume is a commentary on the protective influence of vegetation and on its resistance to erosion. The changes in the rivers since the removal of forests from their headwaters, the increased erosion, the increased destructiveness of floods owing to the greater load of inorganic matter are set forth clearly on almost every page.

This increased load has led the formerly almost limpid streams to aggrade their lower reaches, to convert once fertile bottoms into marshes or to cover them with sand and gravel. This aggrading, in many instances, forced the streams to cut new channels or a network of channels through the plain. But this lateral cutting is prevented now by planting willows, aspens, balm of Gilead and other rapidly-growing plants on the river banks down to the water's edge. The silt-laden flood does little injury to these plants and the plain itself is injured only by drowning of crops when floods come in the growing season. Glenn contrasts conditions in the Coosa and Chattahoochee basins. The former river rises in an area still forested and its waters in flood carry little inorganic matter to cause destruction; but forests have been removed from the headwaters of the latter, floods are more frequent and the accumulation of sand is very great—a condition wholly unknown one hundred years ago.

Rixon⁷ gives similar testimony to the ability of humus to protect itself as well as underlying material from erosion. "The litter and underbrush among the alpine timber are very heavy, having accumulated for ages. One class of timber, having reached maturity, decays, dies and falls, only to be supplanted by another growth, which in time follows its predecessor." This is in a region where rainfalls are infrequent but extremely violent.

Tuomey⁸ studied the influence of forests on surface run-off. His observations were made on four small catchment areas in southern California, where wet and dry seasons are well-marked. In December, 1899, the rainfall was 18 inches. This was at the close of the long dry season, when litter and soil alike were desiccated and each absorbed a large part of the rainfall. The percentage of run-off is given in the first column:

1. Forested	3	35
2. Forested	6	33
3. Forested	6	43
4. Non-forested	40	95

⁷ T. F. Rixon, "Forest Conditions in the Gila River Forest Reservation," *U. S. Geol. Survey, Prof. Paper*, 39, 1905, p. 18.

⁸ J. W. Tuomey, "The Relation of Forests to Stream Flow," *Year Book of U. S. Dep't of Agriculture*, 1903, pp. 279-288.

But in January, February and March, when the absorbed moisture in the litter was great, the contrast still remained, as appears from the second column, where the run-off from the forested areas averages only three eighths while that from the non-forested area was nineteen twentieths.

The great dunes of Bermuda have their advance checked by vegetation. A network of vines creeps over the surface and breaks the force of the wind. Clumps of grass take root in the open spaces and, within a brief period, the heavy rains can do little more than to move the sand a few inches to be piled against the obstacles. Vegetation holds its place on the loose materials until, at length, a dense growth of oleander and cedar render the deluge-like rains wholly ineffective. The same condition exists along railroads within the drift covered areas of the United States. Many of the through cuts are in drift gravels, with no trace of consolidation, yet their walls show the steady advance of plants in spite of rain and the steep slope.

The resistance which vegetation offers to erosion is manifest on a grand scale in the tropics, where growth is luxuriant and the rainfall extreme. The writer has had opportunity to examine at close range fully 200 miles of the Venezuelan and Colombian coast, much of Trinidad, about 50 miles of the Jamaican coast, as well as much of the Pacific coast of Central America. There are some localities where the rock is not consolidated and vegetation cannot maintain itself. Such as gains rooting toward the close of the wet season is killed during the dry season and rain finds only the unprotected surface on which to act. But such areas are of limited extent. The slopes along the coast are usually quite steep and the stratified rocks commonly dip at a high angle. Landslides, owing to this structure, are not rare and they leave a scar on the surface which persists for years; but aside from those merely temporary interruptions, vegetation is practically continuous on even the steepest slopes. The Jamaican conditions are especially instructive. Where vegetation was destroyed by fire in some extensive areas, Guinea grass has taken possession of even the steepest slopes, giving great spaces of bright green, which are notable features of the scenery—and this in

spite of the excessive rainfall. During November of 1909, the rainfall in the mountains of Jamaica was of unprecedented volume, there being at one locality 120 inches in eight days, while in others there were 20 to 30 inches within one day. Banana plantations, with unprotected soil, were washed down the hills and the plants became projectiles with which the flood destroyed vegetation on the lowland; but the forest remained almost uninjured and the litter covering the surface around the trees was practically undisturbed. Where the land was protected by trees, damage was confined to gullies digged by fallen trunks pushed forward by the water. These gullies widened in soft materials and trees, tumbled into the torrent, were carried to the lowland, where they were deposited, *pêle mêle*, with mineral matter on the cultivated land. Nowhere in the whole area was there evidence that rainfall did any serious injury to either forests or the forest litter.

Cornet's⁹ observations in the Congo region are to the same effect. Where the dry season is prolonged, plants are practically dried by desiccation, so that the first rains do great damage; in such localities, this is so serious that vegetation cannot re-establish itself. But, near the equator where rains are almost constant, the forest quickly reoccupies areas which man has cleared. Even in regions with a long dry season, the bottoms of the valleys, owing to dampness, become forested and that puts an end to the action of the wild waters—it may cause even diversion of streams. Clearing of forests lays the humus open and it is carried off to be spread elsewhere, there to enrich the soil. This actually occurs in many valleys, giving what Dupont has termed *terrenoir*; but in the broad alluvial valleys, where humidity prevails throughout the year, vegetable detritus accumulates on the surface and gives a formation of humus *sur place*.

It matters not where one looks, the conditions are the same. Geikie,¹⁰ familiar with the Highlands of Scotland, where bogs in the heath stage cover great areas, says that the surface of a district pro-

⁹ J. Cornet, "Les depots superficiels et l'erosion continentale dans le bassin du Congo," *Bull. Soc. Belge de Géologie*, Vol. X., 1897, Mem., pp. 44-116.

¹⁰ A. Geikie, "Textbook of Geology," 3d Ed., London, 1893, p. 475.

tected by a thin layer of turf, is denuded with extreme slowness except along the lines of its watercourses. Indeed, the evidence is wholly clear to every one who has crossed Scotland by way of the Caledonian canal, which utilizes a chain of small lakes, fed by streams rising in the Highlands and descending with rapid fall. The lakes are not turbid, they rarely show blocks or chunks of peat where the streams enter, the only evidence of vegetable matter being coloration of the water by salts of organic acids leached from the peat. The same condition exists elsewhere in Scottish lakes.

Many years ago, Marsh¹¹ wrote elaborately respecting the protective influence of vegetation and the disastrous consequences following removal of forests. He recognizes that humus can absorb almost twice its weight of water, which it surrenders to the underlying soil and becomes ready to absorb more. Twigs, stems, fallen trunks and the rest oppose the rush of water and break into small streams any larger ones formed by union of petty rivulets. He cites many works, reporting official as well as private studies—all recording the same results.

In the French Department of Lozère, which was among those most seriously injured by the inundation of 1866—caused by rains, not by melting snow—it was remarked everywhere that “grounds covered with wood sustained no damage even on the steepest slopes, while in cleared and cultivated fields the very soil was washed away and the rocks laid bare by the pouring rain.” Marsh cites Foster, who describes an area with slope of 45 degrees, which consisted of three sections: one, luxuriantly wooded, with oak and beech from summit to base; a second, completely cleared; a third, cleared in the upper part but retaining a wooded belt for one fourth of the height from the bottom. The surface rose 1,300 to 1,800 feet above the stream flowing at the foot. The first section was wholly unscarred by the rains; the second showed three ravines, each increasing in width from summit to base; while the third, of same superficial extent, had four ravines widening from the summit to the wooded belt, in which they became narrower and soon disappeared. He

¹¹G. P. Marsh, “The Earth as Modified by Human Action,” New York, 1874, pp. 232–238.

refers to his own observations that, in primitive regions, running streams are generally fringed with trees and that even now in forested areas of the United States trees come almost to the water's edge, so that the banks are but slightly abraded by the current. He cites Doni respecting the Sestajone and Lima, two streams rising in the Tuscan Appenines and flowing into the Serchio. In rainy weather the volume of the former is only about half as much as that of the latter and its water limpid; whereas the water of the latter is turbid, muddy. The drainage areas are almost equal, but the Sestajone winds down between banks clad with firs and beeches, while the Lima flows through a cultivated, treeless valley.

The writer had opportunity in 1910 to observe the effect of heavy rainfall on the steep wooded slopes in central France, where the rocks are resistant gneisses and granites—a condition much like that of the White mountains. The rainfall during that summer was not merely in excess, it was extraordinary. The showers came suddenly and often resembled the cloudbursts of mountain areas within the United States. In many parts of the area, the gorges are deep, with walls often exceeding 35 degrees, at times exceeding 45 degrees. Many gorges have densely wooded walls; many others have a somewhat scanty growth, scattered over the rocky slope with plants growing here and there in decomposed material occupying clefts or accumulated behind projecting craggy points. During some showers, the water ran off exposed places not in rills but often in broad continuous sheets and the streams were converted into roaring torrents. More than once, after one of these almost cataclysmic rains, the writer passed through some of the gorges and was surprised to find that, apparently, no injury had been done to vegetation on even the steepest slopes. Tender plants, growing in handfuls of loose material on projections, seemed to be unharmed. The streams were followed for many miles, but they had received only rare stems of trees from undermined banks and the eddies showed no accumulation of plant material. Trees, lining the streams and in many cases growing down to almost the low water line, gave no evidence of having been subjected to the force of a dashing torrent. The conditions differ from those, with which every one is familiar, only in that they

are on a larger scale. The almost vertical walls of railroad cuts through hard rock are adorned by small plants growing in clefts or even by trees in similar position. These have grown in spite of rains, which threatened to wash away the little soil on which they depend. But the rains are as powerless against plants in railroad cuts as they are against plants growing in like conditions on the walls of Alpine gorges or of canyons in the Sierra and the Rockies.

River Floods.—The floods of rivers have much in common with those of torrents, for most rivers are more or less torrential in their upper reaches; but there are noteworthy differences, aside from those due to volume. The topographical conditions required for torrents are wholly unlike those amid which great rivers exist. Torrents flow, for the most part, in narrow valleys with here and there some wider portions in which are insignificant floodplains; but rivers usually flow in broader valleys, have less rapid descent and are bordered frequently by extensive floodplains. Rivers entering the Atlantic along the eastern coast of the United States empty in most cases into estuaries, which occupy the drowned lower portion of the valley and conceal the floodplain; but the condition is different in the vast interior basin where many great rivers find discharge through the Mississippi channel. Each important tributary of that stream flows for long distances through broad lowlands, which fuse with those of the Mississippi, extending from above Cairo to the Gulf of Mexico and constantly increasing in width toward the south. The coast and the interior types must be considered separately. Illustrations of river floods will be selected mostly from those of the United States, partly because the conditions seem to be unfamiliar to many, and partly because the topographical relations of the central Mississippi region are much like those supposed by some to have existed during the coal-forming periods.

Rivers of the Atlantic Coast.—Shaler,¹² in describing several northward flowing streams of eastern Massachusetts, says that the floodplain is in direct communication with the present margin of the river, so that a very slight rise sends water over the whole of it.

¹² N. S. Shaler, "Fluviatile Swamps of New England," *Amer. Journ. Sci.*, 3d Ser., Vol. XXXIII., 1887, p. 203.

The streams, though draining comparatively small areas, carry an enormous amount of water in flood time. At low water, the river extends for some distance through reedy flats on each side of the flowing stream. The swamps, which are without *Sphagnum*, may be divided into three classes: those, formed in areas so frequently overflowed and so penetrated with water that they cannot afford a site for perennial shrubs, are occupied by rushes in the lower portions and by grasses in the upper; those, occupying a narrow belt in which the grasses give place to various bushy and low growing plants, among which alders are the prevalent forms; then, in some places, a third class, a wide field of swamps, really very wet woods, covered with water not more than twice a year and usually two or three feet above the ordinary inundations. The vegetation is continuous from the lower bench to the wet woods and it is able to resist the flood, though the mass of water is very great and the current very rapid. During flood these streams are almost torrential.

The rivers of Maine tell the same story. The Androscoggin, Kennebec and Penobscot are all liable to sudden floods and the fierce rush of water is reinforced by logs cut for timber. But the banks of those streams are covered with bushes and trees to within a foot and a half of the August stage of water; the flood, though aided by the logs, has not succeeded in tearing out these trees, but the trees have seized the logs, which may be seen for long distances entangled in the bushes. Islands in the Androscoggin have trees 40 feet high, against which the floating timber has lodged.

The Connecticut river, draining a great part of the White mountains as well as of the Massachusetts highlands, flows for nearly 200 miles in a broad valley, rising in terraces. It is subject to great floods, for much of the rugged region around its headwaters has been cleared. The writer has ridden several times for a distance of 150 miles along the banks soon after high floods, which had overflowed the second bottom, 15 to 20 feet above ordinary low water. Loose material, twigs and fallen branches, which had become dry but not decayed, had been removed to be deposited in eddies or on the bottoms. But trees and bushes growing on the lower bottom or on the banks down to within a foot of low water, were not removed.

Many of those are old trees which had withstood floods for more than a century, others were very young; but the age mattered nothing, the sapling resisted as well as did the older tree, provided only that it was rooted in material that would not soften during the flood. One great flood had poured over the second bottom in the late summer when the maize had attained its height. But it did not tear the plants from the soil; pressure against the broad leaves sufficed only to prostrate the plant; none was removed.

At the same time, the effect of the flood was shown by trees on the lower bottom, for those 25 or more feet high, if slender, were bent down stream. Those with broad spreading crowns were affected by pressure at the surface of the current. No doubt, if the flood had been repeated at intervals of two or three days, not a few of those trees would have been overturned; but, once overturned against their neighbors, they would tend to protect the others by increasing the density of the mass and so acting as breakwaters to divide the flow. The flood had no effect where the vegetation was dense, the close growth evidently reducing the current to gentle movement. Croppings of peat bogs, 1 to 3 feet thick, appear at many places in the banks. Such bogs suffer no injury except by undermining; in which case, a floating log occasionally tears off a piece.

The floods of the Passaic in New Jersey and of the Susquehanna have been described in several publications. They are more disastrous than those of the Connecticut, from a pecuniary point of view; but those rivers in flood are no more effective than the Connecticut in the struggle against vegetation.

The Potomac river, though of rather rapid fall, flows in a broad shallow channel, an anomaly due in great degree to the relation between its normal stage and its freshets. The flood of June 1 and 2, 1888, the greatest on record, was described briefly by McGee.¹⁸ The height of water at Washington was no greater than during freshets caused by ice jams, but, above the limit of tidal influence, the volume of water and height of rise exceeded any previously recorded. The

¹⁸ W J McGee, Tenth Ann. Rep. U. S. Geol. Survey, 1890, "Administrative Report," pp. 150-152.

discharge was thirty-eight times as great as that during the abnormally wet summer of 1889; five hundred and seventy-nine times that of the average low water discharge; it closely approximated that of the Mississippi in ordinary years and was two fifths of the discharge by that river during the flood of 1858. At Great Falls, the torrent was one third of a mile wide and 150 feet deep. This was a flood of unprecedented extent, such as might not be repeated in centuries. It should afford full opportunity for determining the ability of floods to remove vegetation. As McGee entered into no detail in his administrative report, the request was made that he would give such information as seemed proper. His letter¹⁴ is in complete detail and the following citations are taken from it.

"The most impressive river flood I ever saw occurred in the Potomac several years ago, when during June a series of rains occurred in such order about the headwaters as to raise the river far above any high stage previously recorded—indeed I inferred from its effect in bending smaller trees in connection with the undisturbed attitude of the older trees that it far exceeded any flood of the preceding 150 years. The discharge was not accurately measured, because the flow was too swift to get a weight into the water, but approximate measurements gave a discharge comparable with that of the Mississippi at ordinary stages. After the water subsided I went over the flooded ground with care; and this is what I found—the bottom being irregular, chiefly wooded, partly in field and pasture; in the woods, trees of less than, say, a foot and a half in diameter, were bent down stream and largely robbed of foliage, and a few were broken off, leaving snags; the higher trees had generally lost branches and most of their foliage (the water having risen forty to sixty feet, or well toward the tops of the highest trees); here and there, especially near the channel, a tree or clump of trees had been uprooted and swept away, though not more than say one or two per cent. of the wood in tree or branch was gone. Here and there in the woods, where the current was concentrated by rocks or large trees, a gully, generally two or three feet deep, as many yards wide and as many rods long, had been cut out; elsewhere, especially where rocks and trees had slackened the local current, there were bars and banks of sand; and generally throughout the woods there was a layer of silt, of course, left chiefly by the subsiding waters overspreading the soil—which usually was unmodified otherwise. From a little field, previously on the bottom, a short distance above Georgetown, the entire crop and the soil to plow-depth or more was removed; and in a sloping and somewhat rocky tract of pasture land, upstream from the field, the sward was irregularly furrowed by gullies ordinarily a few feet deep and as many yards wide—the number being such

¹⁴ Of December 6, 1910.

that perhaps a quarter or perhaps a third of the sward was removed. The furrowing in this pasture, by the way, represents the most extensive flood removal of sward that I have ever seen. Now considering the translocation of material generally by the flood, it is clear that despite the favorable conditions due to abundant vegetation and to a higher declivity of the flood than that of the normal stream, the ratio of organic matter moved to the inorganic sediment was trifling. . . . What is true of that flood is, I am convinced, true of river floods generally—while the flooded river generally has its transportative capacity greatly increased, the material transported is chiefly inorganic, so that the resulting sediments are mainly mud, silt or sand, rather than organic accumulations."

The writer rode through much of the area two months after the flood had subsided. The chief evidence of great flood presented by the vegetation consisted of somewhat inclined trees, deposits of debris in branches of trees at a distance above the stream and an occasional furrow in the sod. These furrows were produced when the water in swirling around a projecting rock worked under the sod and, soaking the materials below, burst the cover, so opening the way for making a gully. In the forested portions, the litter seemed to have suffered very little injury beyond, as noted by McGee, receiving a cover of inorganic sediment.

Murphy¹⁸ has described a flood on Willow creek in Morrow county, Oregon, a stream combining the features of a torrent with those of a river. The creek, 30 to 40 feet wide and enclosed in banks 10 to 15 feet high, has a fall of 38 feet per mile, but, unlike most of such streams, it flows through a fertile valley, 500 to 1,500 feet wide. The storm causing the flood of 1903 was brief, a cloud-burst, and the flood had passed in less than an hour. The water came down as a mass, 20 to 25 feet high, with a slope in front of about 30 degrees, and it was 500 feet wide. It swept away a great part of a town which was in its path. No details are given respecting the damage done to vegetation, but some incidental remarks make the matter sufficiently clear. Referring to methods of determining the high-water level of floods, he says that trees are the best marks; small trees are often bent over and silt or light drift is deposited on them. When the water pressure is removed, the trees straighten up

¹⁸E. C. Murphy, "Destructive Floods in the United States in 1903," U. S. G. S. Water Sup. and Irr. Paper, 96, 1904, pp. 9-12.

and the drifted material is raised above the high level; but rings of silt left on trees, all on approximately the same level, show the true waterline. In this way he determined the extent of the flood. The houses, made of lumber, were lifted from their foundation and were dashed to pieces against rocks or trees.

Wilkes¹⁶ made use of the same method. In speaking of floods on the Willamette river of Oregon, he says that the sudden rises of the stream are remarkable, the perpendicular height of the flood being at times as much as 30 feet, the limit being marked very distinctly on trees along the banks. In New South Wales "near the source of streams, grass is to be seen attached to the trunks of trees thirty feet above the present level of the water, which must have been lodged there by very great floods." This is a commonplace condition; the writer observed it at the head of Sacramento bay in California almost forty-five years ago. He saw many bunches of drift stuff entangled in branches of trees at 10 to 15 feet above the water level, and he was astonished by the fact that so great a flood had done no injury even to the shrubs growing among the trees.

Rivers in Great Interior Basins.—Excellent descriptions of floods within the Mississippi-Missouri area are given in reports of the United States Weather Bureau, those by Morrill and Frankenfield¹⁷ being the most comprehensive.

Man's skill has brought about great changes in the lowlands of the Mississippi. The fertility of that region from the mouth of the Ohio to the Gulf of Mexico early led to settlements at many places. But the periodic floods of the river rendered agricultural operations precarious and levees were constructed for protection. Eventually the construction of such levees was assumed by the Federal government and they now protect a vast area from overflow. The region, now exposed to devastation under ordinary circumstances, is very small, but, during abnormal floods, the levees sometimes give way and

¹⁶ C. Wilkes, "Narrative of the United States Exploring Expedition," 1845, Vol. IV., p. 358; II., p. 269.

¹⁷ P. Morrill, "Floods of the Mississippi River," Rep. Chief of Weather Bureau for 1896-7, Washington, 1897, pp. 371-431. H. C. Frankenfield, "The Floods of the Spring of 1903 in the Mississippi Watershed," Weather Bureau Bull., 1904.

crevasses are formed—at times half a mile wide—through which a stream pours with amazing velocity. The conditions are materially different from those prior to settlement of the region, when the floodwaters spread over an area of 100,000 or more square miles; the energy of the flood stream, when it bursts through a crevasse, is much greater than when there were no levees. This, however, is unimportant, for if the later floods are incompetent to inflict serious injury upon lands protected by vegetable cover, the incompetence must have been more marked when the natural conditions existed.

The protection afforded by levees is shown by constant decrease in extent of the flooded area; the flood of 1887 overflowed almost 30,000 square miles below the mouth of the Ohio; that of 1897 covered somewhat more than 13,000, while the area was reduced in 1903 to somewhat less than 7,000—and in this year the extent would have been much less if the new levees at critical localities had been completed so as to resist the very high water. Rivers carrying much detritus and subject to flood build low levees in their passage through the lowlands. The Mississippi constructed such ridges for long distances, thus preventing return of the floodwater, much of which is ponded in swamps and gradually finds its way to the river farther down. This secondary drainage complicates the problem of reclamation.

The Mississippi floods, unlike those of the Nile, are very complex, for below the mouth of the Ohio the river receives great tributaries from the east and the west, whose floods rarely coincide; while the upper Mississippi, receiving the Missouri and other rivers, has its own periods of flood. The source of floodwaters is in the continental storms, arising in the west or southwest and moving toward the east-northeast. The effects are felt first in the lower Mississippi, which is filled by streams entering from the west; the storm advances to the western ridges of the Appalachian where rise streams forming the Ohio, Cumberland and Tennessee rivers. The heavier rains on the Appalachians pour out chiefly through the Ohio but the other streams contribute a great mass. Important floods in the eastern tributaries occur in the spring months, when heavy rains are reinforced by melting snow. The upper Mississippi is not an impor-

tant factor in respect of quantity, but its swell, coming later than the others, often prolongs the stage of high water. The western rivers, entering below the mouth of the Ohio, are the Arkansas, Red, Ouachita and Yazoo, all of which descend into lowlands, where they meander for a long distance before reaching the Mississippi. The condition in this drainage area is that of rapidly flowing streams emerging from highlands on an immense area of lowland, most of which, unless protected, is subject to overflow.

Both Frankenfield and Morrill emphasize the gradual rise of floods within the open area. Frankenfield gives the record for 1903. The gauge showed at

	Feet.		Feet.		Feet
Cairo, Jan. 28,	17.5	March 8,	45	March 15,	50.6
Memphis, Feb. 1,	10.8	Feb. 22,	33	Mar. 20,	40.1
Vicksburg, Feb. 4,	21.0	Mar. 3,	45		
New Orleans, Feb. 8,	9.1	Feb. 26,	16	Apr. 6,	20.4

The advance was deliberate, the first wave requiring four days for passage from Cairo (at the mouth of the Ohio) to Memphis and seven days thence to New Orleans. The rise was gradual at Cairo, being a foot and a half daily for 39 days to March 8—which was thought to be remarkably rapid—and much less thereafter to the crest; at Memphis, it was one foot for 21 days and only one fourth of a foot for each of the remaining 28; at Vicksburg, barely nine tenths of a foot during each of the first 27 days; while at New Orleans, the daily rise averaged little more than one fifth of a foot throughout the whole period. The great mass of the water came from the Ohio, but the Red and Ouachita, entering from the west, were abnormally high; at New Orleans, the water was at or above danger line for 85 days.

When one studies the reports of local observers, as given in the publications from which this synopsis is taken, he is surprised by the nature and extent of damage within the flooded areas. Artificial protection is almost unknown along the upper Mississippi (above Cairo) as well as along the Missouri and its tributaries. Floods have free course in the low-lying prairie regions of Illinois, Iowa and Kansas as well as in portions of Missouri, and there one should expect to find record of the greater disaster. Morrill has compared

the flood of 1897 with its predecessors as far back as 1858 and he has given details in all parts of the drainage area for that of 1897.

In 1897, the Ohio river was out of its banks everywhere from Pittsburgh to Cairo and the tributary streams, also in high flood, were miles wide for long distances, the "bottom," at times, being covered with 20 feet of water, while the overflow reached into the upper portions of cities along the banks. At the mouth of the river, the lowland was flooded for 4 to 6 weeks and the city of Paducah in Kentucky was flooded for 7 weeks. The river rose 50 to 60 feet along the whole distance of more than 600 miles from Pittsburgh to Cairo. Similar conditions prevailed along the Tennessee river, which for 60 miles was 2 miles wide, reaching to the hills on both sides. In the upper Mississippi region, the river spread from bluff to bluff, 3 miles wide for 147 miles along the Iowa border, and a great area of farming land in that state was inundated. Imperfect levees gave way and along the Illinois river an area of 500 square miles was flooded, making a continuous body of water from the Illinois to the Mississippi. Central Arkansas was submerged for long distances along the Arkansas river; while below Cairo, several levees gave way and the flooded district in that region embraced more than 13,000 square miles.

When one comes to sum up the effect of this disastrous flood, as given by the local observers, he discovers, that as far as the geologist is concerned, they were comparatively insignificant. The damage to manufacturing interests by destruction of machinery and by deposits of mud in mills was very great; the railroads lost much through washing out of embankments, the ruin of bridges and the removal of ties and lumber; but loss to the farming population was only moderate because Weather Bureau warnings led them to transfer movable property to higher land. Small houses, barns, lumber and other loose material were floated off to be used as battering rams against bridges; but, for the most part, farms overflowed by the rapid current were little injured. Where wheat had come up, it was drowned, not removed; where seed had been sown, it rotted; where the flood became sluggish, it left a deposit of sand, which made the land worthless, but elsewhere, as soon as the water withdrew, the farmer

immediately set about replanting. The great flood had done little injury, had hardly disturbed the soil of cultivated fields.

Frankenfield tells the same story for the flood of 1903. The sunken area of New Madrid was filled and the water, being more or less ponded, left deposits of sand. In the lower Mississippi area, crevasses permitted great overflow, but there was no injury to farms, aside from drowning of the crops, for which there was ample compensation in the form of a rich alluvial deposit. The Ohio river was more than two miles wide in many places between Cairo and Louisville. Near Evansville, Indiana, 300,000 acres of maize and 30,000 acres of wheat were covered, but the only loss was that of 3,000 acres by drowning. The local observer at Evansville reported that the damage would have been much greater if the water had not remained in constant motion. At Topeka in Kansas, the flood was diverted from the river by obstructions piled against a railroad bridge and the water, loaded with sand, swept over a wide area. Crops were ruined and the nursery fields near Topeka were covered with sand which buried the young trees. These instances are merely illustrations of conditions prevailing throughout the whole area.

The reports contain no reference to the disastrous effects of such floods upon areas covered with forest or otherwise protected by close vegetable growth, which at first glance seemed strange, because wooded areas occupy much of the lowland or bottom regions. But the omission was due not to neglect but to absence of anything to record. Reproductions of photographs given by Frankenfield and Morrill show that trees and even shrubs were undisturbed amid the rush of water and coarse sand. The writer asked the former for information respecting the matter. The reply was

"During the Mississippi floods no forests are uprooted and no bogs are torn away. A considerable quantity of sand is sometimes carried down and deposited when the velocity of the water decreases, either by contact with obstruction or by reason of decrease in inclination of the floodplain. It is of course conceivable that the mass of water rushing through a crevasse carries away a quantity of vegetable matter and perhaps some trees, but the area would necessarily be limited. The true Mississippi flood moves along very sedately, carrying only the enormous amount of alluvial matter in suspension, but very little indeed of foreign matter. Previous to the era of levee con-

struction, the forests do not appear to have been seriously disturbed by floods."

An observation by McGee¹⁸ is in place here. The Mississippi, as it flows past northeastern Iowa, meanders through a densely wooded floodplain, four or five miles wide, now in one main and half a dozen subordinate streams and yet again in numerous large and small channels. But this plain is flooded each year; according to writers already cited, the river at times covers the whole plain from bluff to bluff as a rapid stream.

Lyell,¹⁹ in referring to the 1844 crevasse near New Orleans, says that the water poured through at the rate of ten miles an hour, inundating the low cultivated lands and sucking in several flat boats, which were carried over "the watery waste" into a dense swamp forest. He mentions that the great Carthage crevasse was open during eight weeks and that nothing was visible above the flood except the tops of cypress trees growing in the swamp.

Humphreys and Abbot²⁰ state that the bottoms of the Illinois river are two to ten miles wide and raised only a few feet above the usual level of the river. The greatest part of this swampy country is included in the "American bottom." The Kaskaskia flows with crooked course through a heavily wooded alluvial bottom, overflowed eight or ten feet by freshets. These authors emphasize the fact, too often ignored, that lowland areas are usually well soaked by rains preceding the floods and the swampy areas become covered with water, so that when the overflow comes, it finds everything prepared for resistance.

Lyell²¹ had the weird experience of descending the Alabama river in time of high flood. At night the passengers were startled by crashing of glass and partial destruction of the steamer's upper

¹⁸ W J McGee, "Pleistocene History of Northeastern Iowa," Eleventh Ann. Rep. U. S. Geol. Survey, 1891, p. 204.

¹⁹ C. Lyell, "Second Visit to the United States of North America," London, 1850, Vol. II., p. 169.

²⁰ A. A. Humphreys and H. L. Abbot, "Report upon the Physics and Hydraulics of the Mississippi River," Reprint, Washington, 1876, pp. 38, 66, 76, 82.

²¹ C. Lyell, "Second Visit," etc., Vol. II., pp. 51, 141.

works. The boat had "got among the trees." The river banks are fringed with canes over which deciduous cypresses tower, while farther back is the evergreen pine forest. During floodtime, the actual channel is very narrow, as the branches of the high trees stretch far over the water, so that, when the stream has risen 40 or 50 feet, much skill is required to keep the way between them. At that time, the adjoining swamps and lowlands are inundated far and wide. But this flood does practically no injury to the forest directly in the path of its strongest current or to that farther back where the current is less rapid. Lyell found the same condition on the Mississippi delta, where the flood waters, though laden with silt, have not injured even the willow saplings.

The floods of great rivers in other lands exhibit the same phenomena.

According to Humboldt,²² the floods of the Orinoco begin soon after the vernal equinox and attain their maximum in July. The water remains at practically the same height until August 25, after which it falls more slowly than it rose. Its bounding region is much like that of the lower Mississippi and the flooded area is as large as England though less than the exposed region along the Mississippi. The delta area is always wet except in some petty elevations, which are dry for brief periods. The surface is completely inundated during several months each year. But it is covered with a dense growth of Mauritius palm in which the inhabitants construct raised platforms, on which they reside.

Wallace²³ has described the broad level area extending to 20 or 30 miles from the main stream of the Amazon and extending for long distances along the main tributaries. This is flooded at every time of high water. It is "covered with a dense forest of lofty trees, whose stems are every year, during six months, from ten to forty feet under water." Much of the flooded area at the mouth of the Amazon is covered with the mirite palms, *Mauritia flexuosa* and *M. vinifera*.

²² A. Humboldt, "Personal Narrative," Bohn Eng. Ed., 1852, Vol. III., p. 8.

²³ A. R. Wallace, "A Narrative of Travels on the Amazon and Rio Negro," London, 1853, pp. 419, 436.

Kuntze²⁴ sailed along the Lourenço river through the vast wooded swamp occupying three degrees of latitude. The remarkable feature, for him, was the absence of transported vegetable detritus. Rare fragments of the swamp are torn off during high water, but these consist not of detritus but of living plants; and these fragments become stranded elsewhere or go to sea broken into bits. The river water is brownish. Everywhere on the Paraguay as well as on its tropical and subtropical tributaries, one finds the dense forests coming down to the river, which are overflowed during floodtime; yet there is no outgoing organic detritus except fragmentary driftwood from trees, which tumbled in from undermined banks. Kuntze followed all the great streams above the mouth of the Parana.

Livingstone²⁵ has given admirable illustrations of the resistance offered by vegetation. Many times he encountered the rivers in flood, when water spread far over the plains. The conditions within the area of the Chobe and in that of the Lecambye are of the familiar type. He reached the Leeba river at the beginning of the rainy season. The river is bordered by a plain, at least 20 miles wide, where, at that time, the water was already ankle deep in the shallower parts, while on the Lobale plain it was thigh deep and impassable. This flooding was not due to the river, for that had not overflowed its banks. The condition was the same as that observed prior to the coming of great floods in the Mississippi lowlands. The Lobale plains are too nearly level to permit the rain water to flow off rapidly; while the thick sward, so dense as to conceal the water, prevents furrowing of the surface and formation of rivulets. On approaching the Kasai river, he crossed valleys, half a mile to a mile or more in width, with clear fast-flowing water almost chin deep. One, half a mile wide, was deeper and the men crossed it by seizing the tails of their oxen. The extremely rapid current "soon dashed them against the opposite bank." The middle of the flood was where a rivulet exists during most of the year. Boggy places are extensive

²⁴ O. Kuntze, "Geogenetische Beiträge," Leipzig, 1895, pp. 67, 68.

²⁵ D. Livingstone, "Missionary Travels and Researches in South Africa," New York, 1858, pp. 191-195, 234, 235, 333, 363, 364, 392.

on both sides of the river, but "even here, though the rapidity of the current was very considerable, the thick sward of grass was 'laid' flat along the sides of the stream and the soil was not abraded so much as to discolor the flood." In his later work,²⁸ he offers an explanation of the conditions.

"The shallow valleys, along the sides of which the villages are dotted, have, at certain seasons of the year, rivers flowing through them, which at this time formed only a succession of pools, with boggy and sedgy plains between. When the sun is vertical over any part of the tropics on his way south, the first rains begin to fall and the effect of these, though copious, is usually only to fill the bogs and pools. When on his way north he again crosses the same spot, we have the great rains of the year, and the pools and bogs, being already filled, overflow and produce the great floods which mark the Zambesi, and probably in the same manner cause the inundations of the Nile. The luxuriant vegetation, which the partial desiccation of many of these rivers annually allows to grow, protects these bottoms and banks from abrasion, and hence the comparative clearness of the water in the greater floods."

Darwin and Mrs. Agassiz tell a similar story respecting the Parana and the Amazon; Cameron and Stanley have shown the conditions in the region of Lake Tanganika and the Sudd of the Nile has been described by Baker, Willey and other travellers. Everywhere, the conditions are the same; living vegetation and even humus are practically proof against the action of floods.

The Plant Materials Transported by Rivers.—While it is true that a vegetable cover is an almost complete protection against erosion and that neither rain nor floods have much ability to remove rooted plants or to take off the superficial coat of decayed or decaying plant-stuff, still the fact remains that rivers do carry away great quantities of plant materials in one form or another. The quantity brought down by a single torrent may be insignificant; even that borne by a river of considerable size may not impress an observer as important; but when one reaches the lower Mississippi, draining an area of not less than 1,250,000 square miles, fed by tributaries from the Rockies at the west and the Appalachians at the east, which flow for long distances in broad alluvial plains, he finds a

²⁸ "Narrative of an Expedition to the Zambesi and its Tributaries." New York, 1866, p. 554.

mass which seems to be almost inconceivably great. On some streams he finds or learns of huge log barricades, apparently affording ample confirmation of Ochsenius's barricade theory; along others the river bed is set with "snags," impeding navigation; while along the main stream the casual observer is apt to regard the floating trees and other débris as an almost continuous mass.

It is equally certain that a vast amount of finely divided vegetable matter, derived from chafing of logs and trunks during their voyage as well as from partial decay of the floating plants, is carried by all rivers. It is true that studies of the Mississippi, in flood and in ordinary stages, have shown that the quantity in the silts is utterly insignificant when compared with the inorganic materials, but it suffices, during decay, to give off a notable discharge of gas in the outer area of the delta. The suggestion has been made that vegetable matter, minutely divided, may explain the fertility of the Nile deposits. According to Reclus, cited by Marsh,²⁷ it has been computed that the Durance river, fed by torrents of great erosive power, carries down annually enough solid matter to cover 272,000 acres with a deposit two fifths of an inch thick, containing more available nitrogen than 110,000 tons of guano and more carbon than could be assimilated by 121,000 acres of woodland in one year. The black waters of the Scottish lakes, of several rivers in Florida, of great rivers like the Congo in Africa, the Negro and others in South America prove that an enormous amount of vegetable material is leached from peaty deposits.

When one considers the mass of transported timber, the content of organic matter removed by solution, and reads the more or less crude estimates of organic stuffs in the detritus carried by rivers, the mind is staggered and he is almost ready to concede that in this transportation there is the process fully competent to bring about the accumulation of coal beds. It is important, then, to ascertain, if possible, what becomes of this material.

The trees and shrubs carried by the rivers were not uprooted by the torrents; they come not from abrupt slopes but from lowlands where meandering streams undermine their banks and the plants

²⁷ G. P. Marsh, "The Earth as Modified by Human Action," p. 245.

tumble in with the rest. Gibbs,²⁸ who saw the spring flood of the Yukon river in Alaska, relates that

"During the high stage of water, which lasts for perhaps two or three weeks, great sections of the heavily wooded banks are undermined and swept away. The majestic spruce trees and tamaracks and birches, which covered them, topple over and are swept down by the current along with immense quantities of drift wood from the forest beds. The entire accumulation, amounting to thousands of cords of wood, is discharged into Bering sea, whose restless waves and shifting winds scatter this fuel and pile it on barren shores, hundreds of miles distant."

The conditions along the Mississippi-Missouri and their tributaries are the same; when the weakened banks cave, the forest, with its fallen trunks and litter, finds its way into the water. The masses of drifted wood in the channels of the Mississippi and some of the streams entering that river from the west have been mentioned in nearly all textbooks on geology during the last seventy-five years; but in most instances the descriptions have been incomplete, while in some cases they were sufficiently inaccurate to be misleading.

In the early days, great numbers of waterlogged trees were held back by their roots and were moored in the silt with their usually branchless stems pointing down stream. These were the "snags" which rendered navigation perilous. Fewer of them are encountered now because a very great part of the drainage area is under cultivation, but enough are added annually to necessitate the services of several snag-removing boats along the line of nearly 2,000 miles. Most of the floating stems find their way to the Gulf, but some are stranded on the delta during floods. At one time, however, they were diverted, in chief part, into the Atchafalaya, the first great arm of the river at the head of the delta.

Darby²⁹ has told us that the vast number of trees brought down by the Mississippi were thrown into this arm, through which they were carried with tremendous speed. The Atchafalaya raft began to form in 1778, when practically the whole drainage area of the

²⁸ G. Gibbs, "The Break-up of the Yukon," *Nat. Geog. Mag.*, Vol. XVII., 1906, pp. 268-272.

²⁹ W. Darby, "A Geographical Description of the State of Louisiana," 2d Ed., New York, 1817, pp. 131-133.

river had still its virgin forest, there being only a few, insignificant settlements west from the Alleghany mountains. By 1816, the head of the raft was within 27 miles of the Mississippi. Darby examined it in that year and reported that it was 20 miles long, 220 yards wide and perhaps 8 feet deep. As it was not continuous, but showed many open spaces, he was convinced that a length of 10 miles would be nearer the truth, thus giving about 4,000,000 cubic yards of loose material as the total accumulation during almost 40 years, practically the total supply of floated timber from the area of more than 800,000 square miles. He says that "the tales which have been related respecting this phenomenon, its having timber of large size and in many places being compact enough for horses to cross, are entirely void of truth. The raft, from frequent change of position, renders the growth of large timber impossible. Some small willows and other aquatic bushes are frequently seen among the trees but are too often destroyed by the shifting of the mass to attain any considerable size." The channel was opened by the state authorities in 1840 and the raft disappeared.

Details respecting variation of position and duration of material were not given by those who described the Atchafalaya raft. But no such lack of information exists respecting the more celebrated raft of the Red river in Louisiana. That stream, formed by tributaries rising in the higher lands of Texas and Oklahoma, flows for a long distance through a region of yielding materials, which, in many places, is densely forested. According to Veatch,⁸⁰ this raft began to form in the fifteenth century and by the beginning of the sixteenth, its head was near the present town of Alexandria, somewhat more than 60 miles from the Mississippi river. It consisted of a series of complex logjams, each filling the channel. These ponded the river, which found a new outlet above the raft, so that this, by additions, gradually moved stream, becoming a great irregular accumulation of logjams and open water about 160 miles long.

⁸⁰ A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," U. S. G. S. Professional Paper, 46, 1906, p. 60.

At the time of the early settlements, the foot of the raft was at Natchitoches, 120 or 130 miles from the Mississippi.

Humphreys and Abbot,⁸¹ writing in 1861, reported that the raft was an enormous accumulation of drift logs, some floating, some sunken. The rotting of the logs at the lower end and fresh accessions at the upper end led to advance up stream at the rate of from one mile and a half to two miles each year, while the retreat at the lower end was about equal to the gain above. At one time, the lower end was at Natchitoches but in 1854 it was at 53 miles above Shreveport, a retreat of about 150 miles. At that time, it was nearly 13 miles long. Above Shreveport to the raft, the river bed was strewn with logs, stumps and other vegetable débris. The river is very shallow, 3 to 4 feet deep at low water, and it was about 220 yards wide at the head of the raft, 405 miles from the Mississippi. Rotting would cause the 13 miles, reported by Humphreys and Abbot, to disappear within seven or eight years.

The notes given by Humphreys and Abbot were from a casual examination by their assistant, the matter lying outside of the scope of their work. The raft was a serious obstruction to navigation, cutting off the region above from communication with the Mississippi. Congress in 1871 ordered a complete survey, which was made by Lieutenant Woodruff, whose report, rendered in 1872, gave the first exact information respecting the actual conditions. Captain Howell,⁸² in transmitting the report, remarks that the facts have been misapprehended even by engineers. "The 'great raft' itself dwindles to a mere pigmy in comparison with the popular notion of its extent and composition." Woodruff, in 1871, proved that the raft extended along the river for about seven miles, but that throughout that distance the channel is only partially obstructed. The whole mass of floating raft was but 290 acres and the whole area of "towheads" or raft resting on the bottom was 103 acres. The towheads are formed during freshets by accumulations of logs and drift around a "snag." As the water falls, the pile rests on the bottom and a

⁸¹ A. A. Humphreys and H. L. Abbot, "Physics and Hydraulics," etc., 1876, pp. 21-23.

⁸² C. W. Howell, 42d Congress, 2d Session, Exec. Doc., 76, p. 1.

rapid deposition of mud takes place around it. The surface left above water produces willows, which, growing rapidly and binding the mass together by their roots, protect it from the washing by subsequent freshets. Woodruff advised removal of the raft, but, to prevent renewal, he recommended that the narrow part of the river, in which the raft was forming, be cleared of the willows lining the banks, which obstructed the passage of large bodies of floating drift. If this were done, the banks, no longer protected by the vegetable growth, would cave readily, the river would be widened and the formations of raft would cease. The removal of the raft was completed in 1872 and Woodruff afterwards gave a full history of the obstruction, to which the reader is referred for other details.⁸³

Franklin⁸⁴ found much floating timber on the Athabasca river in northwestern Canada. "The river carries away yearly large portions of soil, which increases its breadth and diminishes its depth, rendering the water so muddy that it is hardly drinkable. Whole forests of timber are floated down the stream and choke the channels between the islands at its mouth." It is clear that, on the Athabasca as on the Mississippi, caving banks yield the supply of drifting timber. In the same volume, Richardson⁸⁵ describes conditions observed along some rivers and lakes within the region traversed by Franklin's expedition. His statements have been cited by many writers but so far as the present writer has seen, not in full. They are as follows, with omission only of some details which are irrelevant here. Peace river brings much large drift timber into Slave river

"and as the trees retain their roots, which are often loaded with earth and stones, they readily sink when water-soaked and, accumulating in the eddies, form shoals which ultimately augment into islands. A thicket of small willows covers the new-formed island as soon as it appears above water and their fibrous roots serve to bind the whole firmly together. The trunks of the trees gradually decay until they are converted into a blackish substance

⁸³ E. A. Woodruff, in App. Q, Ann. Rep. Chief of Engineers for 1873, Separate, pp. 45-61.

⁸⁴ J. Franklin, "Narrative of a Journey to the Shores of the Polar Sea," London, 1823, pp. 192, 357, 364, 374, 381.

⁸⁵ J. Richardson, *Ibid.*, p. 518.

resembling peat, but which still retains more or less of the fibrous structure of the wood, and layers of this often alternate with layers of clay and sand, the whole being penetrated to the depth of four or five yards or more by the long fibrous roots of the willows. A deposition of this kind, with the aid of a little infiltration of bituminous matter, would produce an excellent imitation of coal, with vegetable impressions of the willow roots. The same operation goes on in a much more magnificent scale in the lakes. A shoal of many miles in extent is formed on the south side of Athabasca lake by the drift timber and vegetable débris brought down by the Elk river; and the Slave lake itself must be filled in process of time by the matters daily conveyed into it from Slave river. Vast quantities of drift timber were buried under the sand at the mouth of the river and enormous piles of it are accumulated on the shore of every part of the lake. The waves washing up much disintegrated vegetable matter, fill the interstices of these entangled masses and in process of time a border of spurious peat is formed around the various bays of the lake."

In a later work,³⁶ referring to the drift timber of Slave river, he describes the trees as "partially denuded of their branches and wholly of their bark." The absence of all-important details in Richardson's account is due to the fact that he was not a geologist, but he was an acute observer, as is evident from the general tenor of his reports. McConnell³⁷ has supplied many of the details omitted by Richardson. The sandy beaches and islands along the lower reaches of Slave river owe their origin to drift timber, which lodges and soon has the growth of willows noted by that author. But those islands cause currents, which either destroy them or move them down stream. Beds of drift timber alternate with clays and sands on many of the islands and in some instances, constitute a considerable portion of the whole mass. The east end of Big island in Great Slave lake is fringed by a wide margin of drift timber. When the interstices have been filled by gradual deposition of sand and the decay of the wood, a dense growth of willows covers it. The coves of the main shore show the same features in many places. Athabasca and Slave lakes are inland seas, larger than Lake Ontario.

Islands, such as those described by Franklin, are not unusual in

³⁶ J. Richardson, "Arctic Searching Expedition," London, 1851, Vol. I., p. 142.

³⁷ R. G. McConnell, Ann. Rep. Geol. Survey of Canada, N. S., Vol. IV., 1890, pp. 63, 64, 74 D.

the Mississippi river. Humphreys and Abbot³⁸ have described the process of formation and destruction:

"Driftwood is lodged upon a sandbar. Deposition of sediment follows. A willow growth succeeds. In high water, more deposition is caused by the resistance thus presented to the current. In low water, the sand blown by the wind lodges among the bushes. An island thus rises gradually to the level of highwater and sometimes even above it, sustaining a dense growth of cottonwoods, willows, etc. By a similar process the island becomes connected with the mainland, or, by a slight change of direction of the current, the underlying sandbar is washed away, the new made land caves into the river, and the island disappears."

When in the temperates such an island, which in spite of current and flood, had grown and had become coated with trees, disappears through undermining, the vegetation floats away piecemeal; but in the tropics the whole mass is bound together firmly by climbing and other plants, whose roots are interlaced and whose stems embrace the trees; so that, when the underlying loose material has been removed, the entangled vegetable matter floats away to be broken up gradually. Many travellers have referred to floating island of plants and plant material. Humboldt saw them on the Orinoco; Mrs. Agassiz was astonished by their size on the Amazon, where some were like "floating gardens, sometimes half an acre in extent." Kuntze saw patches of moderate size floating down the Parana system. Miss Kingsley³⁹ relates that during high water, the Congo and Ogowé tear away their banks in the region above brackish water, where there is no network of mangrove to protect them. Along the Ogowé, the banks are of "stout clay" and the blocks hold together, so that they often go sailing out to sea and are seen far from land with shrubs or even trees on them. Not all reach the open water, for many are stranded in the delta region, where they collect débris from the flood water and become matted with floating grasses. Eventually they all go to pieces.

De la Beche⁴⁰ cites Tuckey's Expedition to the Zaire (Congo)

³⁸ Humphreys and Abbot, *op. cit.*, pp. 97, 98.

³⁹ M. W. Kingsley, "West African Studies," 2d Ed., London, 1901, p. 87.

⁴⁰ H. T. de la Beche, "The Geological Observer," Philadelphia, 1851, p. 370.

as containing the statement that Professor Smith had seen a floating mass about 120 feet long and probably washed out of the Congo, consisting of reeds resembling *Donax* and a species of *Agrostis*, among which branches of a *Justicia* were still growing. Powers⁴¹ saw a floating island in the Gulf Stream in July of 1892. Its area was estimated at about 9,000 square feet and it carried trees, 30 feet high. It was seen again in September, having travelled more than 1,000 nautical miles. This, first seen in latitude 39° 5', may have been torn off from the Florida coast. In every case the floating islands are of small extent and their rarity makes them objects of curious interest.

Driftwood.—Great rivers carry immense quantities of trees from the undermined banks. Where the course of the stream is interrupted by extensive lakes, such as Great Slave or Athabasca, much of the floating timber becomes scattered and is cast on the shore to be mingled with the mineral material, which eventually buries it. When the stream is continuous, some of the drift is cast ashore in eddies, more is stranded during flood time on the delta or in shallows at the mouth; but by far the greater part is swept out to sea, there to be battered by the waves or carried by currents to perhaps distant shores. Nordenskiöld⁴² relates that driftwood in the form of small branches, pieces of roots and whole trees with adhering portions of roots and branches, occurs in such quantity at the bottom of two well-protected coves near Port Dickson, that the seafarer may provide a sufficient stock of fuel without difficulty. The great mass of driftwood carried down by the Yenesei floats out to sea. Some of it is drifted by currents to Nova Zembla, the north coast of Asia, Spitzbergen, perhaps to Greenland. Some of it becomes water-soaked and sinks before reaching those shores. But not all goes to sea, for some sinks in the river bed, upright as though rooted in the sands. A bay off Port Dickson was found barred by a palisade of driftwood.

⁴¹ S. Powers, "Floating Islands," *Pop. Sci. Monthly*, Vol. LXXIX., 1911, pp. 303-307.

⁴² A. E. Nordenskiöld, "The Voyage of the *Vega* around Asia and Europe," New York, 1882, pp. 152-154.

That the amount of driftwood accumulated on shores has been estimated in exaggerated style is amply evident from Brooks's⁴³ observations. In the north and northwest part of Alaska from Norton bay to the mouth of the Mackenzie river, the shore at one time was abundantly supplied with driftwood. The Eskimos, who have been using this wood for generations, are very economical in the matter of fuel and, until the coming of the white man, the probabilities are that the wood accumulated more rapidly than it was consumed. This driftwood is brought down from the interior by the larger rivers, whose banks are forested. The cutting of wood along the banks of the Yukon has already diminished the contribution to the northern Bering sea. The north Arctic coast, eastward from Point Barrow, which is thinly populated by natives and rarely visited by the white man, has some driftwood, but according to Franklin, the quantity is unimportant along the coast visited by him; the material is brought down by the Mackenzie and is carried eastwardly by a strong current. McClure found driftwood on the northeast coast of Banks land, where it is often at a considerable distance above sea level. Low⁴⁴ found that the prevailing winds and the force of the waves have determined the accumulation of driftwood on the shores of Hudson Bay. During great storms, the older, the lighter portions of the mass are thrown to a considerable height above mean tide.

The driftwood deposits on the northern side of Spitzbergen, on Jan Mayen and Iceland are mentioned in most of the current textbooks of geology. Some of them, such as the Suturbrander of Iceland and the deposit on the New Siberia islands are clearly not driftwood, at least not the driftwood under consideration, as they contain fruits and tender portions of plants and belong to the Tertiary. As to the others, of undoubted modern origin, the common conception is simply misconception. The descriptions, in many cases, would lead one to suppose that the mass is closely packed and almost con-

⁴³ A. H. Brooks, "The Coal Resources of Alaska," Twenty-second Ann. Rep. U. S. Geol. Survey, 1902, Part III., p. 570.

⁴⁴ A. P. Low, Ann. Rep. Geol. Surv. Canada, N. S., Vol. III., 1889, p. 33 J.

tinuous. Potonié⁴⁵ has given reproductions of two photographs, one from Jan Mayen and the other by Nathorst from Amsterdam island. The drift material is scattered irregularly, as one should expect, with here and there a considerable pile. The fragments, some of which are very large, are thoroughly battered—the whole resembling very closely what one sees on the gravel flats of rivers subject to flood.

Crantz⁴⁶ was among the first to describe the driftwood deposits of Greenland and adjacent regions, and his statements have been cited again and again, acquiring the increment which usually comes with frequent repetition. In the driftwood on those shores he saw many great trees, which had been torn out by the roots and which, through driving and dashing amid the ice for many years, had been deprived of bark and branches and had been bored by worms. A small part of this débris consisted of willows, alders and birches from bays in southern Greenland; with these were aspens from some more distant region; but the predominant forms are pine and fir with great abundance of a fine grained wood, with few branches, which he took to be larch. With these is a reddish wood of agreeable odor, resembling the Zirbel of the Alps. The grouping shows that the trees came from a fertile but cool or alpine region.

The drift could not have come from the American coast at the southwest as the current is contrary; it must have come with the icy current. It is most plentiful on the coast of Iceland and, on the southwest side of Jan Mayen in N. L. 75°, there are two bays in which there is so much wood, driven in by the ice, that a ship might be loaded with it. He thinks the wood may have come from Siberia, where pine and cedar abound, though it may have come from the west coast of North America by way of Bering strait.

Crantz may be right or wrong in his suggestion respecting the source of the material; that is unimportant. His description shows that the mass, though considerable, is comparatively insignificant. The accumulation on the Jan Mayen bays, instead of being a closely

⁴⁵ H. Potonié, "Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt," Berlin, Funfte Aufl., 1910, p. 126; *Naturwiss.-Wochenschrift*, Vol. IV., Part 4.

⁴⁶ D. Crantz, "The History of Greenland," Eng. Trans., London, 1820, Vol. I., pp. 35-37.

packed deposit, was merely enough to load a Danish merchantman of one hundred years ago—say a vessel of 400 or 500 tons. The description shows also that the wood had floated long; it matters not whether it came by the slow drift from Siberia or Norway to northern Greenland and thence southward, or followed the north coast eastward to Davis strait, it is certain that the voyage was very long and the wood showed the effects. This long continued buoyancy of the wood is equally evident in the Gulf of Mexico, where one finds the Mississippi drift wood stranded on the shores along hundreds of miles.

In all extensive deposits of driftwood, the trees are battered, stripped of leaves, bark and often of branches; they are scattered on the strand or piled in irregular loose heaps, where, exposed to the air, they decay; or if in more favorable conditions, the interstices become filled with sediment, the trees become merely logs in shale or sandstone, even their genus being unrecognizable except by microscopic study of the structure.

The quantity of finely divided organic matter transported by rivers is minute in comparison with that of inorganic. Pourtales⁴⁷ examined sediment from samples of Mississippi water collected at Carrollton, Louisiana. The first series, taken in March during a flood from the Red and Ohio rivers, yielded no matter of organic origin aside from some spicules of sponges and rare vegetable fibers. A second series, collected in June, during a Missouri flood giving the most abundant sediment of the year, contained in water from the surface some indistinct vegetable fibers and wood cells, but no remains of vegetables were found in the other samples taken at various depths. A third series, in August, contained a vegetable scale or a leaf of moss; while a fourth series, in October, contained no organic matter. A fifth series, collected in the following January, showed on nearly all the filters minute black bodies which may have been pollen or spores.

But the absolute quantity of organic matter carried out is considerable. The "mud lumps" off the mouth of the Mississippi, are masses of tough clay, occasionally forming islands of several acres,

⁴⁷ L. F. Pourtales, in Humphreys and Abbot, Appendix 8, p. 651.

which rise 3 to 10 feet above the water and give off much inflammable gas. They were studied by Sidell⁴⁸ for the Mississippi survey of 1838 and by Humphreys and Abbot at a later time. Sidell believed that in outflow of the river the finest materials, organic matter and silt, went farthest and, after deposition, were covered with coarser materials. Decomposition of the organic matter generates gas, which lifts the overlying deposits. According to Humphreys and Abbot, the mud lumps are formed on the crests of bars and their activity ceases when the gas is exhausted. In 1858, during operations for removal of obstructions, some mud lumps on the bar of Southwest pass were broken by an explosion of gunpowder. Strong ebullition of gas continued over a wide area for 20 minutes after the explosion and the surface of the bar, in a space, 100 feet diameter, sank, assuming the form of an extinct crater. Hilgard⁴⁹ gives as composition of gas from one of the mud lumps, marsh gas, 86.20, carbon dioxide, 9.41, and nitrogen, 4.39, which closely resembles the average composition of gas from swamps. Oxygen is absent.

Very little of the vegetable material is stranded on the banks of rivers, comparatively little is deposited on the deltas. Most of the great accumulations in the Mississippi delta, supposed at one time to be driftwood, have proved to be buried forests in place. Terrace deposits along the Monongahela, in Pennsylvania and West Virginia, contain only here and there a woody fragment in the mass of sand, clay, gravel and blocks of rock. The same is true of terrace deposits generally, away from the lines of abandoned curves. In this connection, Brown's⁵⁰ observations along the Amazon are instructive. Long lines of cliffs, now on one side, now on the other, are composed of bright-colored deposits, contrasting with the monotonous clay banks of the river. The elevated plateau of these old river deposits, as well as the alluvial plain, is covered with luxuriant forest. Except a narrow strip along the bank, the whole plain is overflowed

⁴⁸ Humphreys and Abbot, op. cit., pp. 485, 486; W. H. Sidell, Ibid., Appendix A, p. 499.

⁴⁹ E. W. Hilgard, "The Exceptional Nature of the Mississippi Delta," *Science*, N. S., Vol. XXIV., 1906, p. 865.

⁵⁰ C. B. Brown, "On the Ancient River Deposit of the Amazon," *Q. J. Geol. Soc.*, Vol. XXXV., 1879, pp. 763-777.

during the periodical floods. The cliff crests are from 10 to 160 feet above the floodmark and sections show white, yellow and red sands with bluish or variegated clay beds. Ten feet of red clay was seen at the top of one section, while in another are white clays resting on bright red clays. The area studied by Brown is about 400 by 1,000 miles. Within this he saw four insignificant exhibitions of vegetable matter in the deposits, which seem to have been laid down in an estuary.

It is evident that very little of the drifted material is deposited anywhere within the river region or immediately beyond; the driftwood deposits on the northern shores, though vast in the aggregate, clearly represent but a small part of the timber brought down by the great northward flowing rivers; the writer has followed the Gulf Stream for more than 3,000 miles but he has rarely seen floating logs; in the central part of the so-called Sargasso sea of the north Atlantic, he saw no floating timber and captains of steamships familiar with that area have assured him that driftwood is of rare occurrence; the Orinoco brings down great numbers of trees which should be caught by the westward current, but the writer, during two voyages between Trinidad and Colon, saw not one. What, then, becomes of the vegetable material carried down by the rivers?

Deep sea soundings in the Atlantic ocean give no answer to the question. Material brought up by the trawl seems to be practically free from vegetable matter. It has been suggested that the constant "creep" at great depths maintains the supply of oxygen, which under the pressure would be greater than at the surface, so that organic matter would be destroyed. Whether or not the explanation be in this suggestion, it is certain that where different conditions of movement and pressure exist, one finds an accumulation of vegetable material on the ocean bottom. The observations by Agassiz²¹ in the Gulf of Mexico and the Caribbean as well as in the Pacific off the coast of Mexico are final in respect to this matter. His statement is that

²¹ A. Agassiz, "Three Cruises of the *Blake*," *Bull. Mus. Comp. Zool.*, Vol. XIV., p. 291; "General Sketch of the Expedition of the *Albatross*, 1901," Vol. XXXIII., p. 12.

"While dredging to the leeward of the Caribbean islands, we could not fail to notice the large accumulation of vegetable matter and of land *débris* brought up from deep water many miles from the shore. It was not an uncommon thing to find at a depth of over one thousand fathoms, ten or fifteen miles from land, masses of leaves, pieces of bamboo and sugar cane, dead land shells and other land *débris*, undoubtedly blown out to sea by the prevailing trade winds. We frequently found on the surface masses of vegetation, more or less waterlogged and ready to sink."

The violent hurricanes of the Caribbean, as described by Maury, must contribute very largely to the mass of vegetable material. Agassiz found similar conditions at the bottom of the Pacific during the cruise of the Albatross, when he was surprised at the distance to which land-derived material had been carried. Along most of the distance between Acapulco and the Galapagos islands as well as all along the coast from Acapulco northward to within the Gulf of California, there is a very sticky mud covering the bottom and interfering seriously with the work of dredging. His description of conditions between Acapulco and the Galapagos is

"Nearly everywhere along our second line of exploration, except on face of the Galapagos slope, we trawled along a bottom either muddy or composed of Globigerina ooze, more or less contaminated with terrigenous deposits and frequently covered with a great amount of decayed vegetable matter. We scarcely made a trawl which did not bring up a considerable amount of decayed vegetable matter and frequently logs, branches, twigs, seeds, leaves, fruits, much as during our first cruise."

The conditions were similar along the continental coast. The trawl was ordinarily well filled with mud along with the usual supply of decayed vegetable matter. Observations of like character have been made by others elsewhere in the Pacific.

In all probability, a great part of the vegetable matter swept out to sea disappears by oxidation at the surface or in the depths; but in favorable localities another great part is deposited in fragmentary condition with fine muds on the bottom, there eventually to form beds of carbonaceous shale.

Conclusions.—The grouping of facts presented in the preceding pages, proving similarity of conditions in all parts of the world, seems to justify the following conclusions:

1. If torrents carry clear water, they produce little effect on

either the rock over which they flow or the vegetation growing on the floor or on the walls. If they carry sand, clay or even fine gravel, vegetable growth on islands, formed by aggradation, resists the flow and causes increased local deposit without material injury to itself. Even fierce mountain torrents sweeping their load of very coarse materials over a dejection cone do not clear the surface from trees.

2. Water of rainfall has practically no ability to remove a cover of living vegetation, even on steep declivities, except indirectly—as by finding access to unconsolidated material below, which may be rendered semi-fluid, so as to move down as a landslide. The heaviest rainfall barely disturbs the cover of litter in a forest; that material breaks the force of the falling drops, it absorbs much of the water, it obstructs the formation of rivulets and protects itself as well as the underlying soil from erosion. Forests are practically uninjured by the heaviest rainfall; even tiny plants, growing in clefts of rocks are equally undisturbed. Rain does not remove the petty deposit of soil on a projecting point of rock, if a tuft of grass has thrust roots into it.

3. River floods in great lowland areas rise slowly, as is shown by the floods of Mississippi, Amazon, Orinoco, Nile and the rivers of central Africa. In passing through forests, those floods lose speed and become merely a quiet overflow with sluggish movement, so that they disturb neither the living growth nor the decomposed litter on the surface. They move the loose dried twigs and leaves, but even those in great part, are transported only a short distance, unless swept into the stream from the bank. The main current itself cannot uproot trees; it cannot even tear loose a floating tree which has lodged against a sandbar directly in the line of strongest flow; but, unless the sandbar be washed away and the tree be set free, that will remain as a “snag,” to become more firmly fixed during each succeeding flood. In most cases, the areas subject to these vast floods are prepared beforehand by heavy rains, whereby the humus cover is soaked and, so to say, cemented to resist the moving water. A dense growth of vegetation forms in the channels of tropical rivers and offers such resistance that even the mightiest

floods are checked as surely as though dammed by a mountain. Logjams are not swept out by the greatest floods, though the accumulation is merely superficial; in spite of floods, they accumulate at the upper end while decaying at the lower. If floating débris enter a lake of moderate size, it finds its way directly to the outlet; but if the lake be large and disturbed by waves, the débris is scattered along the shores. Finely divided organic matter carried out by floods is in minute quantity compared with the mineral matter and it is deposited along with the fine mud.

4. The trees as well as the humus swept out by floods were not uprooted by the running water. Their presence in the current is due to the undermining of banks composed of unconsolidated material, so that trees, humus and the rest fall together into the water to be carried away. The damage thus done is very small—the drift carried by the lower Mississippi being the accumulation from the soft banks of more than 20,000 miles of river, the length of torrential and semi-torrential streams being neglected, as they contribute an insignificant proportion of the mass. The quantity of driftwood in all is unimportant, when one considers the area into which it is swept. Comparatively little lodges on its way down the larger streams and most of that is buried in muds as “towheads” or “snags” or accumulates in rafts to disappear by rotting. A small part is stranded on deltas, far less than has been supposed, for in the Mississippi delta the deposits, supposed to be of driftwood, are now known to be old swamps and forests buried *in situ*. Much finds its way to shores more or less distant where, after having been for long time the plaything of winds and currents, it is cast in battered condition, scattered here in clumps or in individual pieces to decay or to be buried in sands. But the greatest part floats until, in half-rotted condition, after long exposure, it finds its way to the depths of the sea, to litter the bottom in areas, 1,000 to 1,500 fathoms below the surface, where, mingled with remains of marine animals, it will become part of bituminous shales, with here and there a pot of impure coal.

5. The conception that moving water, under any known or recorded conditions, can uproot forests and sweep off peat bogs from

even moderately extensive areas is wholly without basis in fact. One must regard it as originating in medieval descriptions of the devastating force of the Noachic deluge, which became an integral part of religious and romantic literature, so that the conception was accepted as a fundamental truth, needing neither investigation nor proof.

THE PHENOMENA OF PEAT DEPOSITS.

Peat or turf is familiar to those living in the temperate zone. It is an accumulation of vegetable matter undergoing special chemical change because protected from atmospheric oxygen by an excess of moisture. If one examine an old peat bog, he finds the surface covered by plants of various kinds growing on more or less decayed material. This, in its uppermost portion, is brown or yellowish brown, but the tint deepens downward until in the ripe peat it is almost black. At the top, one finds the vegetable structure distinct, but downward that becomes more and more obscure until in the mature peat it cannot be recognized by the unaided eye, and there seems to be only a vegetable mud containing, at times, fragments of slightly changed wood.

Peat-making Plants.—*Sphagnum* is regarded by many authors as the all-important agent in production of peat; and this supposed condition has been utilized more than once to fortify arguments against the suggestion that coal beds originated from growth *in situ*. The prevalence of this misconception is strange, for evidence to the contrary has been presented in many works during the last century.

Darwin²² says that in the Chonos archipelago, S. L. 44° to 46°, every piece of level ground is covered with *Astilia pumata* and *Donatia magellanica*, "which by their joint decay compose a thick bed of elastic peat." In Tierra del Fuego, the former is the chief agent. Fresh leaves appear constantly around the growing stem, while the lower ones decay. Tracing a stem downward into the peat, the old leaves can be seen in all stages of decomposition until the whole has become blended into a confused mass. Every plant

²² C. Darwin, "Journal of Researches," New York, 1846, Vol. II., pp. 24-26.

in the Falkland islands becomes converted into peat. He saw no moss peat anywhere in South America. Thomson⁵³ notes that peat in the Falkland islands is very different from that of northern Europe, cellular plants being almost wanting. It is formed for the most part of roots, matted foliage and stems of *Empetrum rubrum*, a variety of "crowberry" common on Scottish hills; *Myrtus nummularia*, a creeping myrtle; *Caltha appendiculata*, a dwarf species of water marigold; with some sedges and sedge-like plants. The roots, preserved almost unaltered, may be traced downward in the peat for several feet, but finally all structure is obliterated and the whole is reduced to an amorphous structureless mass. Mrs. Brassey's⁵⁴ description of accumulated decayed and decaying vegetation at Borja bay in the Magellan region is in place here, as showing the origin of peat from forest material.

"To penetrate far inland, however, was not so easy, owing to the denseness of the vegetation. Large trees had fallen and rotting where they lay under the influence of the humid atmosphere, had become the birthplace of thousands of other trees, shrubs, mosses and lichens. In fact, in some places, we might be said to be walking on the tops of the trees and first one and then another of the party found his feet slipping through into unknown depths below."

But long prior to Darwin, Al. Brongniart⁵⁵ asserted that the presence of *Sphagnum palustre* is not necessary to the formation of peat. One finds on the banks of the Meuse, below Maestricht, some peats containing only leaves of resinous trees. He contents himself with the observation that all are agreed that, for formation of peat, the essential condition is stagnant water, covering the surface constantly and never completely dried up. Lesquereux⁵⁶ defined peat as a mass of woody plants whose fermentation and, consequently, decomposition were retarded by the presence and the temperature

⁵³ C. Wyville Thomson, "The Atlantic," New York, 1878, Vol. II., p. 185.

⁵⁴ Mrs. Brassey, "Around the World in the Yacht *Sunbeam*," New York, 1883, p. 128.

⁵⁵ Alex. Brongniart, "Traité élémentaire de minéralogie," Paris, 1807, Vol. II., p. 41.

⁵⁶ L. Lesquereux, "Quelques recherches sur les marais tourbeux," *Mem. Soc. des Sci. Nat. Neuchâtel*, Vol. III., 1845, p. 26.

of water. Vogt,⁵⁷ while giving pre-eminence to *Sphagnum*, notes that under favorable circumstances any vegetable substance can be converted into peat, for some peats are formed of grasses and reeds. Heer⁵⁸ assigns to mosses only a subordinate part and asserts that peat originates partly from mosses, partly from water-plants, from swamp plants, especially from grasses and sedges, and partly from woody plants. A. Winchell in 1860 and Grand'Eury in 1882 made the conditions equally clear, while Früh⁵⁹ showed that *Sphagnum* is a late arrival in accumulation of peat.

Peat in the Tropics.—The belief prevails that peat is not produced in the tropics. Jameson,⁶⁰ long ago, asserted that peat is peculiar to cold climates, but not wholly so, for Anderson had received some from Sumatra. It is quite natural to find peaty substances in warm climates for peat at the bottom of a mountain is more decomposed than that at the top; that of southern England more than that of north Scotland; that of France is more coaly than that of England, while no peat is found in the French lowlands except under cover. All of which shows that decomposition increases toward warm climates, until, in the tropics, it is so rapid that masses of peat cannot form.

Früh⁶¹ was unwilling to believe that true peat forms in the tropics. He discusses a great number of reported occurrences in tropical and sub-tropical areas. For him, the observations are incomplete and his conclusions are that, so far as known, there is no important deposit of true autochthonous peat in the lowlands of the tropics; that, within the tropics, formation of peat is in elevated regions, where the climate is that of the temperate zone; that the supposed peat layers, bored through in the alluvium of great trop-

⁵⁷ C. Vogt, "Lehrbuch der Geologie," 2d Aufl., Braunschweig, 1854, Vol. II., p. 110.

⁵⁸ O. Heer, "Die Schieferkohlen von Uetznach und Dürnten," Zurich, 1858, pp. 1-4.

⁵⁹ J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883.

⁶⁰ R. Jameson, "An Outline of the Mineralogy of the Shetland Islands, and of the Island of Arran," Edinburgh, 1798, pp. 151-153.

⁶¹ J. J. Früh und C. Schröter, "Die Moore der Schweiz," Bern, 1904, pp. 134-143.

ical streams, are prevailingly allochthonous. In this last his reference is to the record cited by Lyell,⁶² of a boring in the Ganges delta, which passed through a deposit, having certainly the characteristics of a peat bed. In view of what has been said on preceding pages respecting the accumulation of drifted vegetable matter and of the fact, that the great deposits in the Mississippi delta, formerly supposed to be of drifted material, are of *in situ* origin, one is justified in saying that the testimony of that and other borings cannot be waived aside lightly by the mere assertion of allochthony. The onus of proof is on the one making the assertion.

It is difficult to understand why the *a priori* reasoning that tropical heat should prevent peat formation is thought so conclusive as to make worthless the testimony, which would be accepted as proving the presence of peat in Michigan or north Germany. The conditions of temperature during summer in much of the United States are decidedly tropical; yet peat accumulates. It is true that vegetable matter exposed to moist air must decay more rapidly where the temperature is constantly high than in the temperates, where the hot period is of brief duration; but that has nothing to do with the matter under consideration, for one is concerned with decay of vegetable matter protected from atmospheric action by a plentiful cover of water. *A priori*, one should expect to find peat accumulating in those tropical regions, where the conditions are such as encourage peat-making in the temperates—with only the difference that, owing to the continuous high temperature, complete decomposition should be more rapid and the bog should have the vegetable mud near the surface. But one is not dependent on *a priori* reasoning.

Harper⁶³ notes that it is an error to suppose that peat is confined to cold climates, since high temperature does not prevent its formation if humidity and topography favor. Peat is abundant on the very border of the tropics in Florida, where tropical temperature prevails throughout the year. *Sphagnum* does not occur south from

⁶² C. Lyell, "Principles of Geology," Eleventh Ed., New York, 1872, Vol. I., p. 476.

⁶³ R. M. Harper, "Preliminary Report on the Peat Deposits of Florida," 3d Ann. Rep. State Survey, 1910, pp. 214, 274, 287, 292.

N. L. 29° , but the peat deposits within southern Florida, as far south as lat. $25^{\circ} 30'$, are of great thickness, one dense cypress swamp showing 20 feet. The Everglades of Florida embrace about 7,000 square miles, which must be regarded as considerable. Even between lat. 30° and 31° , there are thick deposits in which *Sphagnum* is wanting or very rare. Cypress, grasses, fern, myrtle make up most of the vegetation and provide material for peat. The water hyacinth, recently introduced into one of the rivers, is now a peat-maker and, in some localities, the peat is composed almost wholly of this plant.

The temperature conditions in the Bermudas are somewhat less severe in summer than in southern Florida, for the summer heat rarely exceeds 84° F. The southwest wind, blowing off the still warm Gulf Stream, prevents low temperature and the humidity is always high. On the main island there are two great swamps, one of which has at least 50 feet of peat. The climate is such that plants of Carboniferous type could grow well, for the banana thrives while palms and the India rubber tree attain great size.

The literature bearing on tropical swamps is very limited. Those swamps, often of vast extent and covered with dense forest, are regarded, rightly or wrongly, as malarial to the last degree, so that they do not invite close examination on the part of travellers. Yet, even in the limited literature, one finds ample proof that, when the necessary condition of topography and continuous moisture prevail, peat does form.

Wall and Sawkins⁶⁴ estimate the swamp area of Trinidad at six per cent. The long dry season is not favorable to the accumulation of peaty materials; yet the Nariva swamp, drained by streams flowing 12 to 15 feet below the general level, has a black soil which after desiccation at 300° F. still yielded 35 per cent. of organic matter. Hartt⁶⁵ found peat in the state of São Salvador, Brazil, S. L. 10° . He states distinctly that he found peat. "A quarter of a mile south

⁶⁴ G. P. Wall and J. G. Sawkins, "Geology of Trinidad," London, 1860, pp. 62, 63.

⁶⁵ C. F. Hartt, "Geology and Physical Geology of Brazil," Boston, 1870, pp. 365, 509.

of the Imbuçahí is such a grass-covered area, and here excavations by the side of the railroad show that a bed of peat has accumulated, which is two feet thick in some places." It is difficult to understand on what grounds a recent writer feels justified in asserting that this is probably bituminous shale. Hartt knew peat and he knew bituminous shale when he saw them. On the authority of the engineer who constructed the railroad in São Paulo, Hartt states that near Tumanduathy the land spreads out between the hills, level as a lake and about two miles wide, covered with deep layers of black soil "fibrous and woody like peat." The railroad was built over the surface of this bog, but no effort was made to determine the thickness of the deposit.

Mrs. Agassiz, cited in another connection, gives evidence respecting present conditions in Brazil. Kuntze⁶⁶ has described the forested swamps on the divide between the Amazon and the Paraguay. High water makes ponds on the broad alluvial plain, in which *Pontederia* and other plants settle. The ponds become filled with silt and humus and a swamp flora, rich in palms, takes possession of the surface. The Lourenço or Cuyaba river, rising in the low divide, unites with the Paraguay at about S. L. 18°. This river, for about three degrees of latitude, flows through the vast wooded Guatos swamp, which Kuntze thinks is, at least in part, a floating bog. He gives no estimate of thickness, but his brief statement leaves no doubt that the mass is very great. The material is true peat, for in another part of his work he speaks of the fragments of peat occasionally torn off from the mass. The invasion of streams by grasses is rapid and complete throughout this region. Kuntze notes this. Morong,⁶⁷ in speaking of his attempt to reach the head of Pilcomayo river in S. L. 22°, says that his progress was stopped in a lagoon, 400 miles from the Paraguay river, by a dense growth of grasses and weeds, one species of the former attaining the height of 5 meters.

The great accumulations in the lowlands of Nicaragua and Costa Rica have been mentioned by several authors and the writer knows

⁶⁶ O. Kuntze, "Geogenetische Beiträge," Leipzig, 1895, pp. 5, 67, 70.

⁶⁷ T. Morong, *Ann. N. Y. Acad. Sci.*, Vol. VII., 1892, pp. 45, 260.

that great swamps with notable depth of vegetable mud abound on the isthmus of Panama.

Livingstone, Cameron and others, already cited, have given abundant evidence that peaty accumulations are numerous and extensive in the wet regions of interior Africa. Lugard,⁶⁸ in describing the region near Albert Edward lake, refers to interminable river swamps and bottomless quagmires, choked with papyrus, which abound in Uganda and Ungoro and cease below about half a degree south from the equator. Miss Kingsley⁶⁹ says that she encountered three types of bog in west Africa. The broad deep bog was the least difficult, as it makes a break in the forest, and the sun's heat bakes a crust over it, on which one may go—if he go quickly; the shallow, knee- or waist-deep bog is little more difficult as one can wade through it; but the deep narrow bog, so shaded that the sun cannot form a crust over it, is the most abundant and the most difficult. "These required great care and took up a great deal of time. Whichever of us happened to be at the head of his party, when we struck one of these, used to go down into the black, batter-like ooze and try to find a ford, going on into it until the slime was up to the chin."

Chevalier⁷⁰ has described an interesting type of peat formation observed in an extended area between the Gulf of Guinea and the sources of the Niger, N. L. 5° to 9°. This great region has many granitic peaks rising to 1,200 or 1,400 meters, but in great part it is a peneplain, 200 to 400 meters above sea level. The southern portion is covered with a dense forest but the northern portion is a savannah with only scattered trees and shrubs. The whole region would be naked rock, were it not for the rôle played by a sedge, *Eriospora pilosa* Benth., which at times covers the rocks to the exclusion of all other forms. It attaches itself to granite and gneiss; the seeds germinate in minute fissures and the roots spread in clusters between thin plates of the rock, altered or decomposed by atmospheric action. When the thin plate of rock has been worn away

⁶⁸ F. D. Lugard, *Scottish Geog. Mag.*, Vol. VIII., 1892, pp. 636-639.

⁶⁹ M. W. Kingsley, "Travels on the Western Coast of Equatorial Africa," *Scott. Geog. Mag.*, Vol. XII., 1896, pp. 119-120.

⁷⁰ A. Chevalier, "Les tourbières de rocher de l'Afrique tropicale," *C. R.*, Vol. 149, 1909, pp. 134-136.

by water, heat or the activity of the plant, this is ready to resist the rains and winds, for its adhesion is complete on the steepest slopes.

After spreading for sometime, the *Eriospora* lifts its rhizomas into the air and sets off branches, each terminated by a bouquet of grass-like leaves, and each year, before the rains, abundant rosettes of leaves and flowering twigs are developed at the end of these rhizomas. At the beginning of the dry season, these leaves wither and soon afterward they are consumed by fires lighted by men or perhaps by lightning; only the bases of the leaves remain; blackened, half-carbonized, this coat thickens around the rhizoma. The growth of the *Eriospora* tufts is apparently very slow, but, as they may live for several centuries, they attain notable dimensions. On the border of the virgin forest, some were seen more than a meter high and half a meter thick at the base. The stem divides midway into vertical branches, themselves dividing, the last division having a diameter of 2 to 3 centimeters.

The tufts are not always in contact, there being at times an interval of even 50 meters, but in these intervals on gentle slopes, one finds a fibrous network, very humic, constituting a veritable bed of peat, 5 to 30 centimeters thick. This peat is formed not only of roots and rhizomas, but also of young colonies of *Eriospora*, killed soon after origin by fire or by lack of light. True mosses appear at high altitudes. On the humid flank of Mount Momry, Chevalier found a *Sphagnum* at 850 to 900 meters above sea level. The *Eriospora* peat covers tens of thousands of hectares in French west Africa. The condition described by Chevalier is not wholly unfamiliar in the temperates, where mosses and other plants cover irregular rocky surfaces and form a coating of peat at times several inches thick. This is seen frequently in the southern Appalachians. It is the Rohhumus or Trockentorf of the Germans.

It was reserved for Potonié⁷¹ to present the final evidence. Finding no available literature giving details respecting moorformation in the tropics, he applied to Koordes, botanist of the Dutch expedition across Sumatra in 1891. Koordes informed him that in old

⁷¹ H. Potonié, "Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt," 5th Aufl., Berlin, 1910, pp. 152-160.

Javan and Sumatran forests, where hard woods grow, fallen trees, many decades old, lie in great numbers and are still in good condition for export. Termites and fungi are effective agents for destruction of wood in the tropics, but the moisture is almost equally effective in preventing the decay. During the Sumatra expedition, Koordes saw a great, always green Flachmoor, with a 30-meters high mixed forest, extending along the Kampar river at more than 90 kilometers from the coast. As Koordes had made no close study, definitive evidence was wanting to prove that this moor had a true peat floor. But Larive made the necessary sounding at Potonié's request and discovered that the peat in this tropical moor is 9 meters thick.

Examination with the microscope proved the presence of phengams; spores or pollen; occasional brown threads belonging possibly to fungi; some resin-like bodies, etc. The high content of silica in the ash explains absence of diatoms in the microscopic preparations. Chemically, the material is a true peat and German experts pronounced it a good fuel. The ash in the dry material is 6.39 per cent. while good north German Flachmoor peat has 5 to 7 per cent. The ash of the Sumatran peat contains 74 per cent. of silica.

Koordes estimated the area of the freshwater swamp on the left bank of the Kampar at 80,000 hectares. At both camps within this swamp, the water was stagnant, dark brown and slightly astringent. Walking over the swamp was possible only because roots of trees covered the surface with a dense network. The character of the growth, as shown in Fig. 52 of Potonié's work, is a clear instance of adaptation such as is seen in the *Taxodium* of the southern United States; for the roots are widespread horizontally just below the surface, uniting into "broom-shaped air roots" and "asparagus-shaped pneumatophores." The trees of the forest are mostly evergreens, 25 to 30 meters high and closely set. The underbrush consists, for the most part, of the same species but its growth is slow, owing to the dense shade. The forms are all dicotyledonous and the flora is wholly of inland type. Grasses, sedges and mosses are practically wanting; it is a forest moor. The stagnant pools, poor in

phenogams because of the dense shade, are comparatively rich in confervae.

It is sufficiently evident that there is nothing in tropical conditions which would prevent the accumulation of peat. Where there is a long dry season, the vegetable matter is exposed as is that in the ordinary upland forest in the temperate regions. The accumulation of the humus cover advances rapidly for a time but at length the waste by oxidation about balances the additions, so that the thickness does not increase, though the trees shed a greater quantity each year. But in a lowland area where the moisture is great, the chemical changes are modified, the loss is diminished and increased supply brings about increased accumulation. Swamps arise, when from any cause the drainage is impeded. Even along the flow of small springs, peat forms when the water is held back from any cause. On extensive areas, such as the coastal plain on the Atlantic side of the United States or the delta of a river like the Mississippi, where at best the drainage is imperfect, the streams being sluggish and often serpentine, the drainage has been hindered still further by vegetation, the moist area was enlarged and swamps of vast extent originated in post-glacial times. The important condition is the constant supply of water; the drainage must be impeded on the surface and through the bed. In the northern part of the United States probably the greater part of the swamps rest on an impervious bed of glacial clay, an underclay; but it is not necessary that the immediately underlying bed be of normally impervious material, for many large swamps have a floor of fine sand.

Harper⁷² penetrated 10 or 12 miles into the Okefinokee swamp of southern Georgia and discovered that the material on which the peat rests is a few feet of Columbia sand overlying the clay, loam or coarse sand of the Grand Gulf formation (Lower Miocene or Upper Oligocene). In some places a "hard pan," colored by vegetable matter and cemented by iron underlies the sand. Sanford⁷³

⁷² R. M. Harper, "Okefinokee Swamp," *Pop. Sci. Month.*, Vol. LXXIV., 1909, p. 596.

⁷³ S. Sanford, "Topography and Geology of Southern Florida," 2d Ann. Rep. Geol. Survey of Florida, 1909, p. 193.

reports that the peat of the Everglades in southern Florida rests on sand, rock or marl. Grisebach, cited by Fröh, endeavored to explain this apparently anomalous condition for north Germany by the suggestion, that, in very wet years, peat may have been formed in that region even on sands and, being itself practically impermeable, it may have prepared the way for a Hochmoor. Be that as it may, the fact remains that a swamp may begin on an apparently permeable surface; the Everglades are at little above sea level, but Okefinokee is 50 miles from the ocean and 115 feet above mean tide—and its mucky peat contains 85 per cent. of combustible material. In this latter case, one must believe that the underlying sand is not far from an impermeable stratum and that it is saturated with moisture or that by absorption of humic acid the sand itself has been rendered impermeable.

Peat and Peaty Materials.—Russell⁷⁴ describes the Alaskan tundra as a swampy, moderately level country having a cover of mosses and lichens with some ferns and many small flowering plants. Below this dense carpet of vegetation is dark humus. Ponds and lakelets abound, surrounded by banks of moss, and occasionally one finds groves of alders and dwarf willows on their borders. The underlying black humus shows few indications of its vegetable origin. It is 2 feet thick at St. Michaels but is 12 feet at a mile farther east. He saw 15 feet on the Yukon and a depth of 150 to 300 feet is assigned to it at the head of Kotzebue sound. The flora of the tundra is essentially cryptogamic, but two species of *Equisetum* flourish with rank luxuriance in great spaces along the Yukon. So vast is this accumulation, in both area and thickness, that Russell ventures to suggest that some coal seams may have had similar origin. If the tundra coast of Alaska should subside, its peat would be covered with sediments and be ready for transformation into lignite or coal. Its associated plants and animals would indicate the climatic conditions, but the overlying sandstone and shale might contain leaves and tree trunks, floated in by rivers from warmer regions.

But where the swamp is forested, especially if the wood resist

⁷⁴ I. C. Russell, "Notes on the Surface Geology of Alaska," *Bull. Geol. Soc. Amer.*, Vol. I., 1890, pp. 125-128.

rapid decay, the change of that material may advance so slowly that long after the softer parts have been reduced to pulp, the more compact materials may remain almost unchanged. The white cedar logs in the New Jersey swamps are so well preserved in many localities as to be serviceable in manufactures, while the thick peat of many swamps in Florida is without commercial value, because it is crowded with cypress stumps and fallen stems. But decay occurs in the softer woods, so that, as v. Gümbel⁷⁵ relates, flattened trunks are found even at a depth of only a meter in loose peat. The flattening was due to rotting, not to pressure.

The newer peat shows distinct felting and Lesquereux⁷⁶ states that this condition is marked even when decomposition is far advanced. In peats formed above the original water-plane, the "emerged peats" of that author, the layers are characteristic, one inch thick at the top but decreasing downward to less than one eighth of an inch. While the older or ripe peat shows no trace of organic structure to the unaided eye, the microscope proves that it is composed of fragments of plants embedded in an amorphous material consisting of humic or ulmic acid, or a mixture of those acids and their salts. He observed that, whenever the growth of the peat was checked by dryness or other causes,

"the upper surface of the peat becomes crusted, hardened and transformed into a thin coating, quite impervious to the entrance of any kind of foreign matter: and it is upon this hard upper crust that the boggy humus forms; or wherever the land becomes resubmerged, a new peat vegetation begins. In which case, such a crust remains as a parting layer between two beds of peat, like the well known clay partings between two coal benches."

v. Gümbel, in the work just cited, asserts that the minute fragments of plants are not only intimately mingled and felted but also, in the denser portions, are bound together and more or less cemented by a humus-like substance, which is soluble in a dilute solution of caustic potash. Peat, treated with this reagent and afterwards dried,

⁷⁵C. W. v. Gümbel, "Beiträge zur Kenntniss der Texturverhältnisse der Mineralkohlen," *Sitz. Berich. d. k. bayer. Akad. d. Wissenschaften. Math-Phys. Kl.*, 1883, p. 126.

⁷⁶L. Lesquereux, 2d Geol. Surv. of Pennsylvania, Ann. Rep. for 1885, p. 118.

frequently falls to powder. v. Gümbel found also, in many peats, deep black coaly parts of plants as small fibers, a form which he terms *Torffaserkohle* and regards as a thoroughly characteristic type.

Peat always contains much water, often 95 per cent., when freshly removed; but a great part of this evaporates on exposure, there remaining in the air-dried material from 10 to 30 per cent., the denser peat retaining the larger quantity. When first taken out, it is plastic but after thorough drying the plasticity is lost. Peat is very porous; v. Gümbel subjected *Sphagnum* peat to a vertical pressure of 6,000 atmospheres and reduced 100 centimeters to 17.7. The compressed material was apparently homogeneous, the streak was lustrous and lamination was distinct on the fractured surface. The reduction was due wholly to compression, obliteration of the pores, for, when moistened with water, the mass swelled to practically the original bulk. This condition, however, may not be constant. The writer has some briquetted peat, made under great pressure and moderate temperature, which has no tendency to swell when moistened. It has lost all plasticity and in sixteen years it has shown no change on the brilliant surface at each end.

Peat, then, consists, aside from introduced sand, clay or calcareous materials, of more or less changed plant tissues, whose organic texture is still recognizable, and of an enclosing substance derived from complete decomposition of plant tissues, which is originally soluble in water but which, on drying or perhaps on oxidation, becomes insoluble.

Fuel peat has from 1 to 25 per cent. of ash. The purest peats contain less mineral matter than is found in the plants whence they are derived; while on the other hand a peat deposit may pass from pure peat into carbonaceous mud and thence into muds almost wholly without trace of carbon. Mills and Rowan⁷ have given ultimate analyses of surface and dense peats from two localities in Ireland, which represent the extremes of high grade fuel.

In each case, the ash is excluded in calculating the other constituents. The same authors give twenty-seven analyses of the ash found in

⁷ E. J. Mills and F. J. Rowan, "Chemical Technology," Philadelphia, 1889, pp. 15-20.

different fuel peats from Ireland, which show, as one should expect, extreme variations, due to local conditions. Potash and soda are in small proportion, varying from 0.146 to 1.667 of potash and from 0.446 to 2.883 of soda, the greater quantity being in the dense peat. Phosphoric acid is present in all but rarely exceeds 2 per cent., whereas sulphuric acid varies from 10 to 44 per cent. Hydrochloric acid is present in small proportion, but approximately that required by the soda. Lime and magnesia are always present, in some cases the former makes up nearly one half of the ash and in others the latter is one sixth. Ferric oxide varies from 6 to 30 per cent. Silica occurs as sand or as soluble silica and alumina is always present, though at times in small quantity. The ash in the samples analyzed varies from 1.120 to 7.898.

	C.	H.	O.	N.	Ash.
1. Surface, Phillipstown	58.69	6.97	32.88	1.41	1.99
2. Surface, Wood of Allen ..	59.92	6.61	32.20	1.25	2.74
3. Dense, Phillipstown	60.47	6.09	32.54	0.88	3.30
4. Dense, Wood of Allen	61.02	5.77	32.40	0.80	7.89

The content of alkalis rarely exceeds 4 per cent. of the ash in New Jersey peats and ordinarily it is less than one and a half per cent.; but calcium carbonate and sulphate are always present in notable quantity, making up from 20 to 30 per cent. of the ash.⁷⁸

Julien⁷⁹ has given a synopsis of the available information respecting the proximate composition of peat. The various organic constituents seem to be of rather indefinite character and their study is attended with serious difficulty. Julien cites an analysis from Hermann, giving composition of a peat obtained near Moscow:

Muck-carbon, nitrolin, plant remains	77.8
Humic acid	17.0
Humus extract	4.0
Ammonia	0.25
Crenic acids	Trace
Ash	1.25

⁷⁸ W. E. McCourt, "A Report on the Peat Deposits of Northern New Jersey," Ann. Rep. Geol. Surv. of New Jersey for 1905, p. 227.

⁷⁹ A. A. Julien, "On the Geological Action of the Humus Acids," *Proc. A. A. A. S. for 1879*, pp. 314-324, 329, 331, 353.

But in peat from another locality, the process of change was different:

Muck-carbon, etc.	80.0
Apocrenic acids	17.0
Crenic acids	1.0
Ash	2.0

Julien notes the difference in ash between peat and the plants whence it is derived. *Sphagnum* has from 3 to 4 per cent. and the peat varies from 1 to 25 per cent. Vohl found only 1.25 per cent. of ash in a Hochmoor or *Sphagnum* peat. In the ash of living plants he found 20 per cent. of alkalies and 42 per cent. of silica, but only 3 to 4 per cent. of each in the peat or in the soil. On the other hand, there was concentration of alumina, ferric oxide and calcium carbonate as well as of phosphoric and sulphuric acids. Pyrite occasionally abounds in peat and its decomposition gives a basic ferric sulphate to the bog iron ores.

Nitrogen is always present in peat, sometimes as much as 3 per cent. Many suggestions have been made to explain its occurrence; but Julien thinks that most probably it has been derived from animals living in the peat or in the soil. The vast number of insect cases found in peat bogs is well known and Scudder has proved that insects were very abundant in the coal period. The nitrogen content is due very largely to the exuviae of insects, and its frequent concentration in the lower layers of bogs may be due to the survival of those exuviae as chitin.

In the humus one finds as inert substances, nitrolin (rotten wood) and humin, which is black and forms the chief constituent of humus; but it is so mingled with nitrolin that its exact composition cannot be determined. Mulder studied humus and humic acid from the black peat of the Haarlem sea; he obtained ulmic acid from rotten wood as well as from the light brown Frisian peat. The formulas of the several acids obtained seemed to be

Humic acid	$C_{20}H_{12}O_6$
Geic acid	$C_{20}H_{12}O_7$
Ulmic acid	$C_{20}H_{14}O_6$

Stern, however, thought humic and ulmic acids isomeric, with the

formula $C_{24}H_{18}O_9$, while Ditmer thought them the same thing, the latter being produced by drying the former.

Humic acid is a colloid and is not absorbed by plants, though its oxidized product, crenic acid, seems to be taken up. Humic acid is very slightly soluble in water at 6° C.; if dried at 120° C. it is much less soluble and if completely dried at a high temperature it is insoluble. Its alkaline salts are readily soluble but those with alkaline earths and metallic oxides are insoluble or nearly so in water, though readily in aqueous alkaline solutions. Calcium humate dissolves in 3,125 parts of water and ferric humate in 5,000 parts, but these form soluble double salts with ammonia. Ulmic and humic acids are rarely free except in bogs. A noteworthy property of humic acid is that, as a colloid, it renders sand impermeable to water.

These feeble acids yield others upon oxidation. Humic gives crenic, which is present in all waters, in rotten wood, in peat and in cultivated soil. Julien has found it, as well as its oxidized product, apocrenic, in American peat. Crenic acid, pale yellow and transparent, is readily soluble in water; in drying, it becomes opaque and blackens when exposed to the light. Alkaline crenates are very soluble but the calcareous salts are only slightly soluble. Those of iron and aluminium are insoluble, but, according to Bischoff, the iron salt is soluble in ammonia, so that it may be dissolved in the presence of decaying nitrogenous substances. The apocrenates have same distribution as the crenates but they are less soluble. These organic acids bleach clays and have solvent effect on silica; the most efficient being the brown or ulmic constituents.

Liebig,⁸⁰ writing soon after Mulder published the results of his investigations, stated that a solution of caustic potash blackens in contact with vegetable mould. Dilute sulphuric acid precipitates from the solution a light, flocculent brown or black substance which absorbs oxygen rapidly. After drying it is not soluble in water. Cold water dissolves only one ten-thousandth of its weight from vegetable mould and the dissolved material is chiefly salts; but boiling water extracts several substances, yellow or yellow-brown. On

⁸⁰ J. Liebig, "Chemistry in its Application to Agriculture and Physiology," Philadelphia, 1843, pp. 112, 113.

exposure, the solution becomes darker and a flocculent deposit is produced. If the yellowish solution be evaporated to dryness and the residue be heated to redness, this becomes black and, when treated with water, yields potassium carbonate. Evidently, boiling water extracts a substance which owes its solubility to alkaline salts contained in plants. Leibig says, on authority of Sprengel, that humic acid becomes insoluble when dried in air or when frozen in moist condition.

Hunt⁸¹ has remarked that organic matters in solution acting on insoluble peroxide of iron form the protoxide, which is soluble in carbonic acid and in excess of the organic (acid) matter. In this way, great quantities of iron may be removed and white clay or sandstone may be produced. The iron salts become oxidized and go down as hydrated peroxide. Manganese deposits are formed in similar fashion. He is inclined to believe that hydrated alumina may originate in the same way. Organic matter dissolved by surface waters reduces sulphates to sulphides and these, decomposed in turn by carbonic acid, yield alkaline and earthy carbonates as well as hydrogen sulphide.

One finds in bogs some types of peat to which the descriptions thus far given do not apply. Examined in detail, these in some cases suggest original differences due to mode of accumulation or to character of material, while in others they appear to be due to secondary processes.

Long ago, Caspary described the Lebertorf obtained at Purpesseln, near Gumbinnen in east Prussia. This material was studied very carefully by v. Gümbel,⁸² his specimens being from the type locality. The deposit is 5 feet thick and at 10 feet below the surface. When damp, it is liver-brown in color and dense, but when dry it divides into paper-like laminæ. Under the microscope it proves to be composed of very fragmentary parts of plants within a felt-like, flocky mass, in which are insects, recognizable grass and moss, scattered black wood cells, many spores and an immense quan-

⁸¹ T. Sterry Hunt, "Chemical and Geological Essays," Boston, 1875. pp. 97-99.

⁸² C. W. v. Gümbel, *op. cit.*, pp. 131, 132, 133.

tity of pollen. Two specimens from other localities agree in that the cross-section shows a comparatively dense mass of boghead-like material, deep brown in color. One contains well preserved remains of leaves and other organs and the other contains some freshwater mollusks. The granular, felt-like mass, treated with reagents, breaks up and then one sees fragments of woody material, seeds, mosses, and above all pollen grains, several thousands to the cubic millimeter. This substance bears remarkable resemblance to cannel.

Blattertorf, so named from its foliated structure, is closely allied to Lebertorf. v. Gümbel has described a specimen from the kurishen lowland south from Nidden. This mass, in extraordinarily thin laminæ, is composed of numerous bright lamellæ alternating with dull layers, recalling by their luster, pitch and glance coals. The bright material comes from ribs and the harder parts of plants, the grass leaves, which compose the chief mass. Along with those are bits of moss, bast fibers, etc., in the felt-like mass, as well as an astonishing number of pollen granules.

The results of Früh's⁸⁸ studies were published in the same year with those of v. Gümbel. His conclusions respecting the composition of Lebertorf differ somewhat from those reached by v. Gümbel. One rarely finds in ordinary peat any remains of freshwater algæ. But Früh finds that those algæ do not decompose so readily as one might imagine; yet in the ordinary peat they are only rare and accessory constituents, never occurring in such quantity as to be important elements. At the same time there are types of which they are essential constituents.

The Lebertorf, found in ponds within Prussia, as the basis of the Rasenmoor at Purpesseln and as basis of a Hochmoor at Gumbinnen, is a liver-brown gelatinous mass. That from Jakobau, in west Prussia, consists chiefly of algæ, there being more than 60 species of Chroococcaceæ, Hydrodictææ and Diatomaceæ, with which are found indefinite remains of mosses along with pollen of *Pinus* and *Corylus*. The Torfschiefer of E. Geinitz from Gustrow has a very similar composition. The typical Lebertorf from Purpesseln has recognizable colonies of *Macrocystis*, while that from Niederwyl

⁸⁸ J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883, p. 20.

in Thurgau shows algæ as the chief constituents, with pollen and chitin remains, all felted and embedded in a gelatin-like mass. These Lebertorfs originated in quiet waters or on damp soil, through continuous deposition of gelatinous algæ.

Lebertorf is the same with Faulschlamm or Sapropel of Potonié,⁸⁴ an accumulation of stagnant water organisms, animals as well as plants, a formation characteristic of pools in swamps. The fresh-water algæ multiply with such rapidity that eventually a great mass may be deposited. Potonié says that there are lakes in south Germany so filled with Sapropel that they cannot be navigated. Caspary, cited by Früh, conceives that there is no peat-filled lake, on whose bottom this material does not exist. He found it about 9 meters thick at one locality. Früh has given a synopsis in his later work of studies by the students of northern Europe which show the wide distribution of this material. But Lebertorf or Sapropel, so closely resembling cannel in appearance, is not the mass of peat; it is wholly local, originating in open ponds or lakes. The gelatinous algæ are of comparatively rare occurrence in true peat, which owes its origin to plants of wholly different type.

The substance, known as Dopplerite, was described by Haidinger in 1851 and was studied in great detail by v. Gümbel in 1858. Its similarity, in some respects, to coal led the latter author to give it the name of Torfpechkohle. It occurs at many localities, so many that it may be regarded as a normal constituent of peat. The first reference to material of this type in America is in a paper by Fairchild,⁸⁵ who obtained some from a bog at Scranton, Pennsylvania. It is described as bright, resembling a firm but brittle jelly and as occurring in branching masses through the ripe or older peat. In drying, it shrinks more than the peat and the color changes from yellowish brown to almost black, finally becoming brown. In structure it resembles coal.

Julien,⁸⁶ discussing Fairchild's communication, asserted that the physical features of the substance, as described, are those of apo-

⁸⁴ H. Potonié, "Die Entstehung," etc., p. 20.

⁸⁵ H. L. Fairchild, *Trans. N. Y. Acad. Sci.*, Vol. I., 1881, p. 73.

⁸⁶ A. A. Julien, *Trans. N. Y. Acad. Sci.*, Vol. I., 1881, pp. 75, 76.

crenic, humic and other organic acids. He was inclined to believe that this material had been produced by the leaching out of soluble salts of organic acids, in part crenates, from the upper part of the bog and their concentration in the denser portions below, where they filled cavities in the peat. The rapid change in color is not the trifling change due to drying, but is a characteristic reaction of crenic acid, due to oxidation and to partial change into apocrenic acid—a feature observed in the acid and in its salts, both in nature and in the laboratory.

Lewis⁸⁷ described the material with more detail. It occurred in swamp muck underlying 8 to 10 feet of peat. Near the bottom and confined wholly to the muck, are irregular veins filled with a black jelly-like elastic substance, in quantity varying from mere stains to streaks, two or three inches wide. When first taken out it is jelly-like, with conchoidal fracture, but on exposure it becomes tougher and more elastic. Under the glass it is brownish red and nearly homogeneous. It is tasteless and odorless, burning slowly and without flame, when fresh. It is insoluble in water, alcohol and ether but is dissolved by caustic potash. Completely dried, it is brittle and coal-like, resembling jet; it burns with a clear yellow flame and no longer softens in water. In composition, it differs from the typical dopplerite in that it contains little more than half as much carbon and very much more oxygen.

Kaufmann, cited by Lewis, regarded dopplerite as a mixture of humus acids and believed that the portion of peat, soluble in caustic potash, is identical with dopplerite. Compact peat contains minute black particles of dopplerite. Peat is merely a mixture of partly decomposed plants with dopplerite, the latter being a homogeneous peat in which all organisms have been decomposed. Kaufmann found that the proportion of material soluble in caustic potash increases with age, a recent peat giving from 25 to 30 per cent., while an old compact peat gave 77 per cent. But in coals, the proportion decreases, from a diluvial brown coal, with 77 per cent., to anthracite in which no portion is soluble. His conception is that, in the forma-

⁸⁷ H. C. Lewis, "On a New Substance Resembling Dopplerite, from a Peat Bog at Scranton," *Proc. Amer. Phil. Soc.*, Vol. XX., 1881, p. 112.

tion of coal from peat, the first step is the formation of dopplerite and the second is a gradual transformation of the latter into a material less soluble in alkalis and richer in carbon. The peculiarities of the Scranton mineral, its low percentage of carbon and its mode of combustion led Lewis to suggest that it may represent an earlier stage in transformation than that of dopplerite.

v. Gümbel,⁸⁸ in giving the results of his later studies, described dopplerite as a yellow brown homogeneous mass without trace of organic structure and enclosing only separated parts of plants. It burns with a sooty flame, thus differing from the Scranton mineral which burns with a clear flame. It dissolves in acid with effervescence; the calcareous matter seems to be combined chemically with the humus-like material. He is inclined to see in dopplerite a substance originating in mere segregation from plant material as the silica of flints is separated from limestone. He looks upon dopplerite as possessing great importance, since in most peats, one finds cementing substances which, optically, physically and chemically, resemble it closely.

Früh,⁸⁹ in his earlier work, already cited, gives an elaborate discussion and reaches conclusions differing very much in some respects from those just given. He asserts that dopplerite exhibits the wholesale formation of ulmin compounds and gives detailed description of its physical and chemical properties to prove that it belongs to the ulmin group. Owing to the large proportion of calcium, he thinks the material pre-eminently a Rasenmoor deposit. On wholly fresh profiles of Rasenmoor at Gonten, Schwantenau and Rothenthurm, he saw in the red-brown peat, brown flakes, one centimeter to one decimeter, so mottling the mass that he termed this type Marmortorf. Very frequently the flakes are associated with a fragment of root or twig, along which water would flow. At Rothenthurm he found the dopplerite first along a root. These brown flocks are always rich in water; the Rasenmoor is always rich in water, a condition which favors homogeneous ulminification of the

⁸⁸ v. Gümbel, *op. cit.*, pp. 129, 130.

⁸⁹ J. J. Früh, *op. cit.*, pp. 64, 68, 69-72.

peat. The brown flocks are sources of dopplerite. There is no sharp separation between dopplerite and the surrounding peat—there is always a passage zone, an intermingling of peat and dopplerite.

The mode of occurrence is variable. In many places, he saw veinlets, one to two meters long and one to five centimeters wide; here and there a vein spreads out from a root—one passed over a thin sandstone and was prolonged horizontally for several meters as a little bed, at most two centimeters thick. At the same place, he observed some wedge-shaped veinlets penetrating the glacial drift to a depth of 3 to 4 centimeters, where it filled cracks in the clay, binding the fragments into a breccia. There were no plant remains in the clay, so that the fine gelatinous dopplerite must have been deposited in already existing cavities. The presence of abundant water being essential to the ulminification, the mineral is found especially in the lower part of the peat. As every plant can become ulminified, dopplerite may occur in any moor, where the temperature and moisture are in proper relation. He has found the mineral derived from *Sphagnum* at the contact between Rasenmoor and Hochmoor, where the water-rich condition existed.

Kaufmann believed that with the point of a knife he separated particles of dopplerite from good peat; Fröh did this with Marmor-torf, but he thinks that even the best Rasenmoortorfs are not usually so far advanced as that. The microscope detects little flakes produced by the flowing together of very tender ulmin material, if the peat be ripe; but one cannot determine whether these are ulmic or humic acid—the quantity is too small. At the same time, he maintains that it is an error to identify with dopplerite the caustic potash extract from peat, as Kaufmann and Muhlberg have done, for potash combines with ulmic and humic acid alike. Dopplerite is a higher member of the ulmin group.

Kinahan⁹⁰ often observed that, when peat was taken out on the hills near Dingle bay, little streams of tar, which had filled tubes made by decay of roots, oozed and trickled out from the newly made

⁹⁰ G. H. Kinahan, Geol. Surv. of Ireland, Explan. of sheets 182, 183, 190, 1861, p. 33.

surfaces. This is clearly the younger stage of dopplerite referred to by Früh.

The Schieferkohle, studied in detail by both v. Gümbel and Früh, is a Quaternary deposit observed at several places in Switzerland. It will be described on a succeeding page. v. Gümbel's⁹¹ type specimens come from Morschwyl, but he studied also specimens from other localities. The mass is partly loose, like peat, partly dense, like pitch coal, containing remains of conifers, birches, etc. It is undeniably peat-like in the less dense portions, where one can recognize mosses and grasses as the predominating constituents. The denser portions are changed by caustic potash into an opaque mass. The microscope shows great quantity of deep brown shell-like splinters of an amorphous textureless substance, which acts as dopplerite. In many parts of plants, the same dark brown material fills the cell spaces. He thinks it not doubtful that the denser condition of this portion of the coal comes from richer accumulation of the amorphous filling material, which he terms Carbohumen. This Schieferkohle contains vast numbers of pine cones, not deformed, and of flattened pieces of wood. In many of the latter, he found an inner woody zone, composed of a soft yellow substance, like rotten wood, while the bark zone had been changed into a shining pitch coal.

Früh,⁹² after studying Schieferkohle from many localities, confirmed the view of Heer, Kaufmann and others that the deposits agree with peat in microscopic character. They are peats more strongly ulminified. He often found the interior of rootlets apparently little changed, but after a few minutes exposure, they began to change and at length became brown like the Marmortorf. With regard to the wood fragments, he thinks that the outer portion was ulminified early, perhaps before the bog was covered with drift, whereas the inner portion was merely peated. At the same time he does not recognize dopplerite in the Schieferkohle.

It is sufficiently evident that the difference between Früh and the other observers is merely respecting nomenclature. There is agreement on all matters which concern the questions at issue here.

⁹¹ v. Gümbel, *op. cit.*, pp. 136, 137.

⁹² J. J. Früh, *op. cit.*, pp. 83, 84.

This is placed beyond doubt in his later work,⁹³ where he modifies the broad statements made in his earlier work and shows that the difference is formal rather than real. He says that dopplerite originates, as does the peat, out of a varying mass of colloid substances, free humus acids, salts of humus acids, inorganic substances and some nitrogen. So one may regard dopplerite as an ultimate, a humate, a crenate or a mixture of them all, with in addition some inorganic salts. The essential point is that, during the process of peat-making, a greater or less portion of the vegetable material is brought into a condition admitting of flowage, so that it may remain distributed throughout the mass or may be collected into cavities. When the pores of the peat are filled, farther drainage is possible only to a limited degree and the material will find its way to the tissues, becoming the Carbohumen of v. Gümbel. To this absorption of Carbohumen is due the different effect of pressure upon peat and brown coal; in peat the porosity is very great, in brown coal it is small.

Variations in structure or appearance of the peat have been observed in recent bogs, which are as notable as those found in the Schieferkohle. Griffith⁹⁴ in describing the Irish peat bogs, said that bases of the bogs consist of clay covered with a layer of peat, which is composed of rushes and flags. Above this is another bed of peat, closely resembling cannel coal, with conchoidal fracture and hard enough to be worked into snuffboxes. It yields 25 per cent. of ash and much oxide of iron. This, in turn, is covered with black peat containing twigs and branches of fir or pine, oak, yew and hazel, only the bark remaining. Where whole trees were found, the roots had disappeared.

Lesquereux⁹⁵ relates that on the border of the valley of the Locle, a considerable mass of marl covers a bed of peat, which has become converted into lignite, hard, fragile and with brilliant fracture. The thickness on the border is barely 3 inches. Farther downward toward the bottom of the valley, the marl is only 4 feet

⁹³ J. J. Früh, in "Die Moore der Schweiz," 1904, pp. 164, 165, 166, 167.

⁹⁴ Griffith, cited by S. S. Haldeman in Introduction to 2d Ed. of R. C. Taylor's "Statistics of Coal," Philadelphia, 1855, p. 166.

⁹⁵ L. Lesquereux, "Quelques recherches sur les marais tourbeux," Neuchâtel, 1845, p. 95.

thick and the underlying peat, though showing some change, still retains its peaty character and is a passage from the lignite of the border to the peat now worked in the open valley. One is left to conclude that the deposit is continuous from the border to the uncovered peat.

The Characteristics of Peat Accumulations.—Swamp or marsh accumulations of vegetable matter consist essentially of remains of land plants, including the many water-loving types. Locally, as in the Lebertorfs or Spropels, one finds freshwater algæ and remains of mollusks, while in many swamp peats the exuviae of insects abound, often associated with land mollusks. Some of the older books refer to marine peat. Macculloch⁹⁶ mentioned a peat found in Scotland, which was composed of *Zostera marina*, and several authors have cited this as a marine peat. But *Zostera* is the ordinary "eel-grass" of estuaries and is a land plant able to endure salt water. Al. Brongniart,⁹⁷ under the title "Tourbe marine," states that De Candolle saw in the dunes of Holland some peats which burn well and are composed of seaweeds, notably of *Fucus digitatus*. He, himself, had seen, opposite the rock of Calvados, some extensive beds of brown material, soft and spongy, which had all the external appearance of peat, but it could be burned only with difficulty. That seaweeds may accumulate on a strand, there to form a considerable deposit, is placed beyond doubt by Potonié's description of such an accumulation on Heligoland, of which he gives a photograph. But such deposits are wholly local and possess no importance. Muck,⁹⁸ in the first edition of his work, referred to the occurrence, at several places along the North sea, of peat evidently marine in origin. Samples of the material were sent by him to Früh, who submitted them to microscopic analysis. One consisted almost wholly of decaying seaweed; when dried, it burned with small flame and foul odor, but it showed no characteristic of peat. Another, a brown substance washed up on the shore at Blankenberghe, contained no

⁹⁶ J. Macculloch, "A System of Geology," London, 1831, Vol. II., p. 339.

⁹⁷ Al. Brongniart, "Traité élémentaire de minéralogie," Paris, 1807, Vol. II., pp. 41, 46.

⁹⁸ F. Muck, "Die Chemie der Steinkohle," 2te Aufl., 1891, p. 164, footnote.

trace of algæ, but consisted wholly of fragments from land plants. The same is true of a specimen from the Dollart. After examining samples from all localities of alleged marine peat, Früh felt himself justified in the positive assertion that thus far no marine peat has been discovered.

The classification of peaty deposits has received much attention from many authors. The literature in America is somewhat limited, as, until very recent years, peat seemed likely to remain indefinitely without economic importance. Among the earliest attempts at classification is that by Shaler,⁹⁹ whose grouping was much in detail. He divided the forms into marine marshes and freshwater swamps; the former including grass marshes and mangrove marshes, growing above tide, as well as mud banks and eel-grass marshes, growing below mean tide; the latter including river, lake and upland swamps, each with two subdivisions. The grass marshes are along the coast where salt water bathes the roots of the plants, while freshwater swamps are above tide. Davis,¹⁰⁰ in discussing the freshwater deposits of Michigan, employed the terms bog, marsh and swamp; a bog is an area of wet, porous land, whose soil is mostly decayed or decaying vegetable matter, loosely consolidated and containing so much water as to tremble when one walks on it; the vegetation varies, but usually consists of mosses, sedges or grasses, or a combination of them along with shrubs and even small trees; a marsh does not shake readily when one walks over it, though it may be very soft and wet; the vegetation is mostly grass-like, though shrubs may be present in thickets; a swamp soil is firm, but wet, even to flooding at times, and bears trees and shrubby plants as the most important part of the vegetation. This grouping is not absolute, for the types may all be found in a single basin, the passage from one to the other being very gradual.

In Europe, where peat is of great economic importance, many students have expended great ingenuity in efforts to classify the

⁹⁹ N. S. Shaler, "General Account of Freshwater Morasses of the United States," Tenth Ann. Rep. U. S. Geol. Survey, 1890, pp. 261 et seq.

¹⁰⁰ C. A. Davis, "Peat," Ann. Rep. Geol. Survey of Mich., 1907, pp. 108, 109.

deposits, which are, practically all of them, freshwater, marine marshes being unimportant economically. Lesquereux, in 1845, recognized two general types of bogs, which he termed supraaquatic or emerged and infraaquatic or submerged, the former being above the waterline and the other at or below it. The prevailing classification in Germany recognizes the Hochmoor, equivalent to the Heathermoors of Scotland, and, in great part, to the supraaquatic of Lesquereux; the Wiesenmoor, Grünlandsmoor, Niedermoor, or Rasenmoor, equivalent to the bogmeadows of other lands; and the Waldmoor or forested bog. These are the Lyngmose, Svampmose, Hoermose; the Kjaermose, Engmose; and the Skovmose of the Danish authors. A similar division is that of Hochmoor, Flachmoor and Zwischenmoor, these being the terms employed by Potonié and some recent authors.

Potonié¹⁰¹ has described a great moor in east Prussia on the delta of the Memel and Nemonien rivers, which shows the relations of the several types. Going eastward from the shore, one finds first the mud, which on the border is held by water lilies and other plants, referred to as "landmakers" because they are outposts. Higher plants, especially canes, occupy water areas, behind which there develops a meadow Flachmoor of sedges, where frequent floodings prevent growth of trees. Beyond that, foresting begins, and one reaches a moor of black alder, several kilometers broad. The surface is occupied by swamp plants, such as *Iris*, *Sium*, sedges, which endure well the periodical floodings of this zone. If the area were one of gradual subsidence, equal to the accumulation, the condition would continue for a long period. The surface rises gently and one comes to another flora, accustomed to somewhat drier soil, with alders, hops and nettles. Thus far, one has followed the Flachmoor or Niedermoor; but at a little distance beyond, swamp birches are seen among the alders. The latter soon disappear and the birch zone is reached, beyond which is a zone of forest with *Pinus sylvestris* and *Picea excelsa*. These form the Zwischenmoor or Waldmoor.

In this passage zone, the peat has risen so high that the surface is dry; the forest is here, but as one advances the trees become

¹⁰¹ H. Potonié, "Die Entstehung," etc., pp. 35-40.

smaller because increasing accumulation of peat deprives them of their nutriment. Even exceptionally high floods cannot bring dissolved nutriment to them and they are dependent on rain, dew and dust. At length, the trees are displaced by *Sphagnum*, able to store away dew and rain, to remain moist on even a dry bed, to keep the area wet though it may be several meters above the water level. So one, in going eastward, is still on wet land. This is the Hochmoor, swelling as an hour glass—whence its name. But there is a still higher stage. On the Hochmoor, one's foot sinks deeply into the sphagnum-peat as he advances. At length a pond is reached; the rain collects in pools or small lakes, whence it flows to moisten the surrounding area. Plants thrive here because the changing water gives them nutriment. Reeds and sedges are seen and even *Pinus sylvestris* is present, though much smaller than on the borders of the Flachmoor. This great bog rests on a sandy deposit, with which are mingled the vegetable muds of the kurischen Haff.

As the problem of formation of coal beds is world-wide in scope, the essential features of those beds being practically the same in all lands, the study of peat accumulations must be as broad as possible, if the conclusions are to possess any worth for or against any theory. In the pages to follow, the results of studies by observers in many regions will be presented in detail. This may involve some repetition, but that will serve only to emphasize the importance of certain conditions, which have been overlooked or ignored in some contributions to the discussion.

Peat Deposits in the United States of America.—Marine marshes exist in extensive areas along the Atlantic coast from Maine to Florida, a region believed by nearly all observers to be subsiding. North from Florida, the tidal marshes are grass-meadows, ordinarily treeless. They are covered with grasses, reeds or coarse sedges and the upper surface is near the level of high water. Cook¹⁰² has described those of New Jersey, which are typical of the whole coast from Georgia northward. Alongside of streams crossing the marshes there is a narrow ridge of dry land, but within a few yards one

¹⁰² G. H. Cook, "Geology of New Jersey," 1868, pp. 24, 231, 233, 238, 300, 347-350, 361.

reaches the permanently wet area. Immediately below its sod, is mud or soft earth, which varies greatly in composition. Near the creeks, it is usually fine clayey mud with embedded roots, the whole evidently transported material; at a little distance, it is black earth or muck, formed in a swamp; while at a greater distance one finds only a mass of fibrous roots and vegetable matter with no admixture of earth or mud. The last two are of *in situ* origin. The "meadows" along the Passaic and Hackensack rivers, emptying into New York harbor, show an extreme thickness of 32 feet of "mud" resting on 8 feet of blue clay, while farther up the stream are great marshes resting on fine sandy material. One sees on the surface of these meadows great numbers of white cedar stumps and the mud is crowded with remains of cedar timber.

The condition is due to encroachment by the sea, whereby the treeless marshes advance inland and overrun the white cedar swamps along the streams; one finds at many places the old cedar forest buried in the tidal marsh, while the cedar swamp still exists at a little way beyond. The salt water kills the freshwater grasses and the trees on the border. In many places trees flourished 80 years ago, where one finds now only salt marsh muck. The white cedar is a very durable wood; trunks of trees killed by the salt water are still standing in localities where several feet of muck have accumulated around them.

Lyell¹⁰⁸ observed the effects of this encroachment in Georgia. In coming down to the coast, he found the trees becoming dwarfed and at length disappearing to be replaced by reeds; but in the marshes he saw the stumps and stools of cypress, still retaining the erect position in which they had grown. He quotes Bartram, who stated that when planters, along the coast of the Carolinas, Georgia and Florida, as well as westward to the Mississippi, bank in the grassy tidal marshes for cultivation, they "cannot sink their drains above three or four feet below the surface, before they come to strata of cypress stumps and other trees, as close together as they now grow in the swamps."

¹⁰⁸ C. Lyell, "Second Visit to the United States of North America," London, 1850, Vol. I., pp. 334-336.

When one reaches southern Florida, he finds a different type of tidal marsh. Northward, grasses and rushes are the plants which advance the land seaward, but at the south the mangrove is the agent. That plant abounds on coasts in tropical America and is found northward in Florida to lat. 30° , though it is not abundant above lat. 26° . The eccentric mode of growth exhibited by the special type under consideration, long ago attracted the attention of botanists. Bancroft¹⁰⁴ says that it rises from several strong woody roots which emerge from the ground for two or three yards before they unite at the trunk. Tough woody shoots, about three inches in circumference, descend from the trunk to take root and, as the tree increases in size, the shoots increase in number. These by their strength compensate for the looseness of the soil. The tree grows in a low, wet soil by the side of running water.

The Florida mangrove flourishes only in contact with salt water, being stunted by brackish water. Vaughan¹⁰⁵ describes it as attaining the height of 10 to 20 feet and as growing in water or so near it that the soil is saturated. The long seeds take root in water not more than one foot deep, leaves being put forth as soon as the surface is reached. Besides the tufty roots given off at the base, there are others originating at higher levels from the stem, which grow downwards and embed themselves in the soil. Shaler says that these can descend through 8 feet of water in order to take root. Each becomes a new tree to be multiplied in similar manner. Thus a tree may advance 20 or more feet in a century, the advance being checked only when the water is too deep or the waves prevent rooting. These growths, as described by Shaler and Vaughan, form dense thickets, a fringe, which is made denser by litter from the trees; so that débris from the land eventually fills up the space behind and the trees are killed. But, in the interval, a new fringe has been formed. In the moist area behind the growth, freshwater types displace the saltwater forms and a swamp results. Shaler

¹⁰⁴ E. Bancroft, "An Essay on the Natural History of Guiana in South America," London, 1779, pp. 76-79.

¹⁰⁵ T. W. Vaughan, "Geologic Work of Mangroves in Southern Florida," *Smithson. Misc. Coll. Quart. Issue*, Vol. V., 1910, pp. 461-464

conceives that the Everglades of southern Florida, with an area of about 7,000 square miles, owe their origin to outward advance of mangroves on shallows of the coast.

The freshwater swamps of the Atlantic and Gulf coasts are, for the most part, sharply distinct from the tidal marshes, even where the latter have encroached. Cook¹⁰⁶ has shown the relation in New Jersey by a section extending from Dennisville to Delaware bay, a distance of about one mile. The cedar¹⁰⁷ swamp begins at the edge of the low upland and gradually deepens to 15 feet. Like most of the cedar swamps in New Jersey, it has been cleared, but clusters of young trees up to 100 years old remain here and there on the surface, which is only a few feet above high tide. The cedar grows densely but slowly. Old stumps show more than 1,000 annual rings, but those near the bark are as thin as paper and the stumps rarely exceed 3 feet diameter, though some have been seen which were 7 feet. The swamp soil is black, peaty, 13 feet thick at Dennisville and, when dry, burns. It shows no admixture of foreign material and contains only 3.35 per cent. of ash, the water in the dried peat being from 12 to 16 per cent. It is very loose and porous, always full of water; the roots of the trees run through it in every direction near the surface, but do not penetrate to the solid ground. Where the peat cover is thin, the roots do pass through to the underlying soil, but, in that case, the wood is inferior and it cannot be utilized in manufactures.

Trunks of trees are buried at all depths and are so numerous that one has difficulty in thrusting a sounding rod to the bottom. Some had been blown over when rotten; others were merely uprooted. Some, blown down, lived for a considerable time afterward. The prostrated trunks lie in all directions and the conditions are precisely the same as those now seen on the surface of the swamp. Large stumps have been found, which grew over logs, now enveloped by

¹⁰⁶ G. H. Cook, *op. cit.*, pp. 301, 302, 355, 356, 360, 361, 484.

¹⁰⁷ The cypress or white cedar of New Jersey is *Chamacyparis thyoides*, which is found in swamps from New Hampshire to Florida and westward to the Mississippi. The bald cypress is *Taxodium distichum*, a form surviving from the middle Tertiary, which extends from southern Delaware along the coast to Texas and up the Mississippi to southern Illinois.

their roots, and at the bottom are found worthless logs of cedar belonging to trees which were rooted in the solid ground below.

Shaler¹⁰⁸ has given a general description of the Dismal Swamp, an area of about 500 square miles, at only a few feet above tide level. It was much larger, but a great part has been reclaimed by draining. The peaty deposit rests on Pliocene sands, of which 10 to 14 feet are exposed on the border; but this is not wholly certain as the bottom has been reached at only one place within the swamp. C. A. Davis has stated recently that the peat is at least 15 feet thick and of good quality. On the western border is Drummond lake, 6 feet deep and somewhat more than 2 miles wide. Shaler says that, here and there within the swamp, one comes to drained areas of considerable size, one of which, embracing about 2 square miles, has long yielded fine crops of maize. He notes that *Sphagnum* has a very small place in this swamp and that it is an unimportant factor everywhere south from the Potomac and Ohio rivers, where the greater heat and decreased rainfall prevent its luxuriant growth. The most important peat-making plants in the region south from those rivers are canes, a grape, the bald cypress and the juniper with, in some localities, the dwarf palmetto—among these, he assigns the chief place to the common cane.

The greater part of the Dismal Swamp is under water during most of the time, but there are elevations rising not more than 3 feet above the general level; yet the drainage due to this slight elevation suffices for growth of pines belonging to the common southern species. In the main area, water-covered, one finds three trees, *Taxodium distichum*, the bald cypress; *Juniperus virginiana*, the juniper; and *Nyssa sylvatica*, the black gum. The juniper occupies spots usually somewhat desiccated during the dry season, but the others, being provided with special appliances, live where their roots are covered with water during even the growing season. The forest is very dense and passage through it is rendered difficult by projecting knees of cypress and the arched roots of *Nyssa*, while everywhere is a profusion of other plants. The surface is covered with a litter

¹⁰⁸ N. S. Shaler, Tenth Ann. Rep. U. S. Geol. Survey, pp. 293, 313, 321, Pl. 8, 9, 10, Fig. 29.

of fallen trunks, twigs and leaves. Shaler's plates from photographs taken in this forested swamp show the conditions thoroughly.

Shaler¹⁰⁹ has described the peculiar modification of structure characterizing the bald cypress. This is the greatest of the conifers east from the Rocky mountains and it is the most stately of all the trees on the eastern half of the continent. On dry ground or where there is no water during the summer half of the year, it shows no peculiarities; but where it lives in swamps, flooded during the growing season, the roots give off excrescences which project above the water, their height depending on the depth of water. These "knees" are subcylindrical and are crowned by a cabbage-shaped expansion of bark, rough without and often hollow within. Whenever these knees become permanently submerged during the growing season, the tree dies; as was proved in the New Madrid area, where, during the 1811 to 1813 earthquakes, the land sank permanently. In Reelfoot lake, within Kentucky and Tennessee, thousands of these long cypress boles still stand in the shallow waters, though 70 years have passed since the slight submergence of their knees. The effect of drowning is shown on a plate in the work previously cited. Many dead stems of cypress rise above the surface of Drummond lake, which is only a few feet deep. Lesquereux thought that these were once part of a floating forest.

Okefinokee swamp in southern Georgia is not wholly a forested swamp. It is larger than Dismal Swamp and more difficult to study. Harper¹¹⁰ succeeded in penetrating it to a distance, all told of about 18 miles. Here and there are islands, raised a little above the swamp level, at times not more than 2 feet, often less. On those the slash pine and the black gum grow, while all around are sphagnous bogs in which are slash pine, as well as swamp cypress, with sedges, ferns, sundews, and pitcher plants. Pines are wanting where the muck is more than 4 feet deep, but the cypress grows densely until the depth exceeds 6 feet. Where that depth is exceeded, no trees are found

¹⁰⁹ N. S. Shaler, "The American Swamp Cypress," *Science*, O. S., Vol. II., 1883, pp. 38-40.

¹¹⁰ R. M. Harper, "Okefinokee Swamp," *Pop. Sci. Monthly*, Vol. LXXIV., 1909, pp. 596-613.

and the surface is a "prairie." This type has an area of 100 square miles in the western part of the swamp, covered everywhere by water in wet weather, so that one may go in any direction in a canoe. Canes, pickerel weed and water lilies abound but *Sphagnum* is absent, as in this latitude it can grow only in shaded places. Stumps of cypress are abundant and the peat is about 10 feet thick. The Florida swamps, described by Harper and others in the official reports, show all types from the open marsh to the forested swamp. The cypress swamps of the Lake region have grass marshes near the water, which are separated from the dense cypress growth by a narrow belt of small willows. The peat in these deposits is worth little commercially, as it is crowded with logs and woody roots. The great Everglades area belongs to the stagnant water type.

The cypress swamps of the Gulf coast are like those of the Atlantic coast. Lyell¹¹¹ relates that, in excavating for the foundations of the New Orleans Gas Works, the contractor soon discovered that he had to deal not with soil but with buried timber; the diggers were replaced by expert axemen. The cypress and other trees were "superimposed one upon the other, in an upright position, with their roots as they grew." The State Surveyor reported that in digging the great canal from Lake Ponchartrain, a cypress swamp was cut, which had filled gradually, "for there were three tiers of stumps in the 9 feet, some of them very old, ranged one above the other; and some of the stumps must have rotted away to the level of the ground in the swamp before the upper ones grew over them."

Conditions in the cypress swamps are the same throughout, whether the prevailing tree be bald cypress or white cedar. The peat is formed by accumulation of litter in the dense forest and, for the most part, the swamps are due to impeded drainage on an almost level surface. The trees are rooted in the swamp material, which at times is of great thickness, more than 150 feet of muck, carrying cypress trees on its surface, being reported from Florida. Such trees find ample nutriment in peat containing less than 4 per cent. of mineral matter and they do not send their roots down to the solid ground. One sees growing amid such conditions not merely shrubs

¹¹¹ C. Lyell, "Second Visit," etc., Vol. II., pp. 136, 137.

but also majestic trees, such as cypress and gum, which, as well as the less imposing juniper, yield wood of great importance to the artificer.

The inland swamps of the northern states differ in many ways from the coastal swamps. They occur along river borders or in lakelet areas of the drift-covered region. In great part, the former are "wet woods" covered more or less deeply with water during several months of each year, but they show considerable stretches of true swamp. The swamps and marshes of the drift region are less extensive, but they afford better opportunity for studies bearing on the mode of accumulation. They have been investigated by C. A. Davis, H. Ries, N. S. Shaler and others, but the most comprehensive and most recent description is by Davis.

Davis¹¹² notes that very few highly organized plants can grow wholly submerged in water, and those are mostly endogens; 10 feet of depth seems to be the limit, although *Potamogeton* has been found rooted in 23 feet; other types, low forms such as *Chara* and the floating algæ are indifferent. Some plants, burweeds, arrowheads, reed grass, pickerel weed and water lilies can grow when partially submerged; while some land plants, shrubs and trees can endure long exposure to water about the roots. The surface growth on swamps is important. Elm and black ash swamps are of common occurrence and have, besides those plants, tamarack, spruce, willows, alders, with various heaths and mosses. They do not always show much peat, but what there is is well decomposed and is apt to contain much mineral matter. The greatest thickness of peat in these swamps is reported to be 10 feet. Tamarack (*Larix laricina*) and white cedar (*Chamaecyparis thyoides*) indicate the presence of peat, the latter growing densely on the surface of a deposit, 20 feet thick. Spruces (*Picea mariana* and *P. brevifolia*) also grow on thick peat; willows, poplar and alders grow on the thickest peat and in wet places; but the mosses, *Hypnum* and *Sphagnum*, grow only in advanced swamps.

¹¹² C. A. Davis, "Peat, Essays on its Origin, Uses and Distribution in Michigan," Rep. Mich. Geol. Survey for 1906, pp. 121-125, 128-134, 136-141, 153, 154, 157-159, 160-166, 203, 204, 208, 213, 269, 275, 279, 291.

Peat deposits fill depressions but, in some cases, are formed on almost level areas. Depressions more than 25 feet deep may be filled by algæ, by floating species of seed-bearing plants, by sedimentation, by plant growth from the sides or by a combination of these processes. A frequent succession is *Chara*-marl, on which rests a peaty soil in which plants take root; the land marsh moves out and tamarack advances on the deeper peat of the shore. As the water becomes shallower, each shore type moves out and is succeeded by the type behind—the water growing warmer and more aerated. Formation of peat on a flat space is much under the same conditions as those on the surface of a filled depression. When the drainage is poor, liverworts or some mosses take possession; if not too wet, rushes, sedges and grasses appear. Accumulation makes the place wetter and only the hardier plants remain. Sedges are the chief peat-producers under these conditions.

The process of filling a depression is often very complicated. In southern Michigan, the early stages are shown in many lakes, which are surrounded by zones of aquatic plants. More or less detritus, organic and inorganic, finds its way into the lake. Where the process is more advanced one can trace the whole succession.

The lowest deposit is formed of *Chara* and floating algæ. This is succeeded in the shallower water by the *Potamogeton* zone and that by the water lilies. Just beyond this one comes to the floating mat of sedges, extending on the water surface to a considerable distance from the shore and buoyant enough to support a considerable weight. The earlier stages may provide soil for rooting of the sedges at the shore line, but the mat itself is wholly unsupported for a considerable distance and is often 18 inches thick. Finely divided material from the undersurface of the mat increases toward the shore, where it becomes dense and the mat is no longer floating. Thus is built the solid peat, structureless, decomposed and nearly black. The surface rises gradually after grounding of the mat and, at each level, new plants appear. Shrubs and *Sphagnum* advance to be overcome in turn by tamarack and spruce, which in their turn are overcome by the marginal flora from behind. Tamarack accompanied by ferns grows far out on the bog.

The final stage is where the sedge mat closes over the surface and the underlying peat has become firm. Sedge is usually the chief factor in the later stages of lake destruction. At times, the mat is pressed down by the weight of trees growing on it. In one case it was found 6 feet thick, resting on semi-fluid peat. A section at one locality showed

	Feet.	Inches.
1. Sphagnum peat	0	6
2. Moss peat and shrubs	2	0
3. Moss peat	0	3
4. Coarse brown peat, stumps and roots...	2	6
5. Remains of shrubs	0	2
6. Dark peat rich in sedge remains.....	2	0

It was impossible to determine the condition farther down as the peat was very wet, but sedges were recognized. Similar conditions were observed in other sections. These all show that the trees were rooted in the mat of pure vegetable material, even when it reposed on the water surface and that, while the trees were growing, the accumulation of peat was continuous.

After the mat has been grounded, *Hypnum* hastens outward from the shore, associated occasionally with some *Sphagnum*. When the surface rises 2 inches above the water level, ferns appear and they are followed by *Sphagnum*, which persists even when the surface is flooded. It is much hardier than *Hypnum* and, for that reason, it has been regarded as chief factor in the production of peat. But it is often absent, having been found in less than 30 per cent. of the localities examined by Davis. The first tree is the tamarack, which grows densely on the level of shrubs, but isolated trees are scattered over the open bog.

Chara-marl occurs frequently in southern Michigan but it was not seen anywhere in the northern portion of the state, where the general succession differs somewhat from that already given. The Chara-stage is wanting; pond weeds, pond lilies and rushes are of irregular occurrence and the sedge-zone is all important. Owing, probably, to absence of fragments belonging to the higher plants, the work of freshwater algæ is more apparent than in the southern

peninsula. Algal lake, now covering only a few acres, is surrounded by a great wooded swamp, extending northeastward to a large lake and coming down almost to the water at the north end of Algal lake. The swamp loosestrife (*Decodon verticillatus*) forms the marginal zone. The bottom of the lake is covered with soft flocculent ooze, composed of unicellular algæ with diatoms as well as pollen from conifers. Davis conceived that peat of this type would be like cannell and he thinks that freshwater algæ may have been more abundant in Carboniferous times, when all types of plant life were lower than now. A similar material was found in a mature bog, where the section is

	Feet.
1. Coarse peat, with stumps, roots and fallen stems.....	5
2. Brown peat, good texture, quite plastic	5
3. Soft, light-colored peat, like that at Algal lake	4

These are the only localities in the United States whence this type of peat has been reported. Ehrenberg, Früh and Potonié have described the felt or Meteorpapier, as Ehrenberg termed it, which remains on swamps after floodwaters have been drained off. Potonié calls it Sapropel carpet, and he has given a photograph showing the material covering land plants of a swamp. But the phenomenon is of by no means rare occurrence in the eastern part of the United States. Davis has communicated by letter that he saw it in 1910 near St. Augustine in Florida, where the water of a swamp had been lowered; the felt was conspicuous on the tussocks, etc. In the Everglades of the same state, he found the felt about the grass and sedge stems in the level swamps. Here and there it contained a considerable quantity of calcareous matter, due perhaps to activities of Cyaphanaceæ present in the algal association. The same type of felt-like development is seen during springtime in marshes of the northern states, where the water drains off slowly. *Spirogyra* and other filamentous algæ sometimes cover the temporary ponds and are left as a felt-like cover when the water has been withdrawn. This felt breaks into small pieces as it dries and is added to the peat. The writer has observed it in very small patches on the New Jersey marshes; he has seen patches more than 10 feet square at many

places in Rhode Island and Massachusetts. But in every case, the quantity is insignificant as compared with the mass of other vegetable material and this algal contribution must be wholly unimportant. At the same time, one can conceive of conditions which could render it important.

Shaler expressed the prevailing opinion when he asserted that the presence of moisture determines the distribution of plant life in swamp areas. Advance of swamp destroys the forest. He had seen many places on the coast of Maine as well as in northern Michigan and Wisconsin, where invasion by *Sphagnum* made the surface so wet that even the most water-loving trees of those regions could not maintain themselves. Davis, in his work on Michigan peats, has discussed the causes leading to the succession of vegetation in swampy areas. The shrubs growing at the water level are drought plants, though living where water is abundant; their leaves are linear or even scale-like; the cuticle is dense and the leaves are protected by a waxy or at times resinous coating—all contrived to prevent too rapid evaporation. The explanation of the condition is complex, but it depends mostly on the difficulty with which moisture can be extracted from peat. Once thoroughly air-dried, peat is almost impervious to water, so that plants growing on peat or a peaty soil suffer more from drought than those on other soils. Even when wet, it has little water for plants growing on it. A noteworthy fact in this connection is that some plants, growing near water level in southern Michigan, are found growing only on dry soils in northern Michigan. They find their drought-resisting ability equally essential in both regions. The distribution of these plants is explained by the fact that they have fleshy fruits, which birds eat during their southward migration and the seeds are scattered over moist areas. While the plants must be able to resist drought, they must be able to endure excess of moisture in some localities. Davis saw *Betula pumilla* and some willows living in places where their roots had been covered with one foot of water for several years.

The conditions of advance described by Davis are familiar in other states. They exist even on high swamp areas, as appears

from Bradley's^{112a} notes on the disappearance of meadows which were used as camping places in the Sierra Nevada. Fifteen years ago, these were open and covered with abundant grass. Originally, they were ponds or lakes which became filled with peat, on which grass thrived. As the material became less wet, tamarack seeds, blown in from the border, took root, but the young shoots were killed by the frequent fires. Since protection against fire has become complete throughout the region, the tamarack has advanced so as to occupy much of the surface, while pines are encroaching, which eventually will crowd out the tamarack and will occupy the whole area. The trees are rooted in the peat.

Bates¹¹³ has shown that swamp conditions and luxuriant growth of trees are not incompatible. In describing the forests of Para, he says that one swampy area was covered with trees more than 100 feet high, all of second growth. In another swamp, the air was marked by a mouldy odor, the trees were lofty and the surface was carpeted with lycopodiums. Farther down in this area, where the ground was more swampy, wild bananas, great palms and exogens grew luxuriantly and were covered with creepers and parasites; while the surface was encumbered with rotting trunks, branches, leaves, and the whole was reeking with moisture. Kuntze, already cited, states that the tropical swamps are densely wooded. Observations by other authors will be referred to in another connection.

Peat Deposits in Europe.—The importance of peat as fuel in Europe has led to thorough investigation of that material from every conceivable standpoint. The literature is so extensive and, in great part, so excellent that one, compelled by limits of space, finds himself embarrassed in selection of authors as well as of matter.

Lesquereux¹¹⁴ long ago proved that *Sphagnum* is not the important factor in peat-making; he recalled attention to Ad. Brongniart's

^{112a} H. C. Bradley, "The Passing of Our Mountain Meadows," *Sierra Club Bull.*, Vol. VIII., 1911, pp. 39-42.

¹¹³ H. W. Bates, "The Naturalist on the River Amazons," London, 1863, Vol. I., pp. 44, 47, 50, 51.

¹¹⁴ L. Lesquereux, "Quelques recherches sur les marais tourbeux," pp. 32, 111, 121, 137; 2d Geol. Surv. Penn., Rep. for 1885, pp. 107-121.

observation that evaporation from that moss is proportionately less than from other plants; and he showed that growth of the moss is checked by freezing and that the plant cannot live in deep shade or under forest trees such as oaks, pines or beeches. He seems to be the first to note that marls covering peat bogs contain impressions of plants.

Lesquereux's conception of the mode of filling depressions from the sides differs somewhat in detail from that given for the United States. Shallow ponds are invaded by vegetation, which forms a mould in which water plants take root. The basin is filled by their decay, the surface becomes humus in which plants of other types grow, giving meadows or forests. The filling is rapid in the early stages. Pools of quiet water are invaded by *confervæ*, mingled with infusoria, microscopic plants and small shells, which by decay cover the bottom. At times, 6 to 10 inches of this deposit may accumulate in a year. When the water is deep, the same result is reached by another process—the prolonged growth of certain floating mosses, especially of some species of *Sphagnum*. Those, pushing out from the sides, form a thin cover, in which grasses, sedges and other water-loving plants grow. Eventually, this becomes compact enough to bear the weight of trees, even of dense forest; until, becoming too heavy, it either breaks or is pressed slowly to the bottom and covered with water. This, he asserts, is no hypothesis but the statement of actual fact.

The lac d'Étaillères, near Fleurir in Switzerland, is open water in an extensive series of peat bogs. Prior to the year 1500, it was the site of a forest; but in that year, according to legend, the forest disappeared and it was replaced by two lakes. The lakes still exist and in quiet water one can see the prostrate trees on the bottom. But a new carpet has already spread over much of the surface, which in turn will become forested and will sink. Thus one may find superimposed beds of decomposing vegetable matter, each consisting of remains of small plants below but of forest remains above. An analogous condition exists in Lake Drummond of the Dismal Swamp, where the bottom consists of a forest cover, once at the top but now

under water, while vegetation is encroaching from the sides. It is quite possible that this explanation of the Lake Drummond condition is correct, but that lake is shallow, only 6 feet, and the trees are erect; in the deeper lac d'Etailières, the trees were prostrated by breaking of the mat. To illustrate the succession in such a case, he gives the section of a bog in Denmark:

	Feet.	Inches.
1. Fibrous yellow peat with undecomposed mosses.....	3	8
2. Oak layer, wood still sound, trunks 2 to 3 ft. diameter.		
3. Peat, yellowish	6	
4. Birches, prostrate, <i>Betula alba</i>	3	0
5. Black peat	4	0
6. Pines, 6 to 10 inches diameter, most of them pointing toward center of the basin, retaining their branches, embedded in a mass of leaves, cones, etc.	8	0
7. Black compact peat	4	0

and the bottom not reached. This peat was mined for fuel, the works being extensive. The general description by Lesquereux shows that the conditions are not wholly the same in his localities as in many areas within the United States. They suffice to show that *Sphagnum* is a late arrival, though in Switzerland, as in some other portions of Europe it is more important than in this country, where sphagnum-peat rarely exceeds 3 feet.

As illustrating this, one may cite Vogt's¹¹⁵ description of a Hochmoor at the Ponts of the Canton Neuenburg. This lies between two villages built on limestone benches on opposite sides of a valley. In the middle ages, each village was visible from the other, but that is no longer the case. The bog has raised itself, hill-like, growing most rapidly along the middle line. This mass is *Sphagnum* and its mode of growth shows well the ability of that moss to retain water, so as to thrive at considerably above the water level.

Heer¹¹⁶ says that life on land began with minute forms and few types. So, in the water, algæ begin the work. Even pure fresh-

¹¹⁵ C. Vogt, "Lehrbuch der Geologie," 2te Aufl., Braunschweig, 1854, Vol. II., p. 110.

¹¹⁶ O. Heer, "Die Schieferkohlen von Utnach und Dürnten," Zurich, 1858, pp. 1-4.

water, exposed to air and light, is full of minute plants, with boundless capacity for multiplication, forming in vast legions, which sink and form a layer of organic material, the basis of formations composed of higher organisms. These are followed by floating mosses, which, in spite of their small size, soon produce a great mass of organic material. The bladderworts, water milfoils follow and the water lilies spread their leaves over the surface; reeds press out from the shore and sedges of various kinds form a wickerwork of roots, which gradually spread over the whole depression and water is no longer visible. Meanwhile the peat has been growing denser, drawing water from below and keeping the bed moist. In it nestle the milfoils and heaths. The lake closed, woody plants encroach, *Betula* and then *Pinus sylvestris*. But the latter does not grow high, breaking off after attaining a certain height and weight, sinking into the underlying soft material, there to be destroyed and converted into peat as are the shrubby plants. These trees are readily overthrown by the wind and the peat is crowded with the overturned trunks of birch and fir. The harder parts offer prolonged resistance to chemical change and are embedded in a pulp-like mass derived from the softer parts. The conditions in all stages are recognizable in Swiss deposits. The succession may be varied by climatic changes, whereby a Waldmoor may be converted into a Torfmoor and that in turn into a Waldmoor again.

Früh's¹¹⁷ descriptions of conditions in Switzerland and Germany are much like those given in later years for localities in the United States, though the succession of events may differ somewhat in detail. At the same time, the Hochmoor or *Sphagnum* deposit seems to be built up on the Rasenmoor, composed of *Cyperaceæ*, *Phragmites* and *Hyppnum*; islands of Hochmoor were seen occasionally in a Rasenmoor. Lorentz is cited as having examined 57 moors, of which 31 were Hochmoors developed on Rasenmoors. Früh investigated Hochmoors in Steiermark, the Bavarian highlands and in Switzerland, all of which showed that *Sphagnum* is a late arrival in

¹¹⁷ J. J. Früh, "Ueber Torf und Dopplerit," pp. 5, 7-9, 15, 18, 20.

the peat. In the great Digenmoors of the Bavarian highlands he found

- | | Meters. |
|---|------------|
| 1. Black peat, with <i>Sphagnum</i> | 1 to 1.2 |
| 2. Homogeneous black-brown, compact, plastic peat, with layers of crushed birch stems; a few specimens of <i>Sphagnum</i> , but 90 per cent. of the mass consisting of roots of <i>Cyperaceae</i> | 1 to 1.5 |
| 3. Wood layer of conifers | 0.4 to 0.6 |
| 4. Glacial drift. | |

He gives measurements from fourteen localities in Switzerland, only one of which failed to show the succession observed in the section. The exception is a Hochmoor without Rasenmoor foundation and resting directly on a layer of wood remains. One group seems to contradict Sendtner's generalization that Hochmoor accumulates only in localities where the water is not calcareous. This, the "Todte Meer," is a typical living Hochmoor, near Willerszell, bearing on its surface many hummocks nearly equal in height and basal diameter, and bordered by a mountain stream, whose drainage area is in a limestone region. It shows

- | | Meters. |
|---|------------|
| 1. Hochmoor, <i>Sphagnum</i> | 0.2 to 0.3 |
| 2. Felted Rasenmoor, upper part consisting of <i>Carex</i> and <i>Arundo</i> , with scattered algæ; lower part with <i>Hypnum</i> | 3 |
| 3. Almost pure well-preserved <i>Hypnum</i> . | |
| 4. Clay and gravel. | |

He finds a simple explanation in the fact that the stream, at high water, does not wet the *Sphagnum*. It may be well to note here that in Michigan, according to Davis, *Sphagnum* is indifferent to the character of the water, the presence of calcium carbonate in no wise affecting its growth.

Früh reports 48 Hochmoors in the Alpine region as originating on Rasenmoors. V. Bemmelen and Staring are cited as having proved the same relations for the provinces of Orenthe, Friesland and Gottingue in Holland. The Rasenmoor does not require hard water, for the vast moors of the Rhine and Maas area are watered by those streams, which contain only 65 and 41 millionths of calcium and magnesium compounds. The relation between Hochmoor and

Rasenmoor is not always apparent as either one may be very thin and the other very thick. In his later, great work on the Swiss moors, Früh has described with much detail all the Swiss deposits and he has offered generalizations which will be considered in another connection.

It had been suggested by some observers that the tree trunks found in the bogs had been drifted into the depressions, but Früh asserts without qualification that they are in place. The condition is wholly normal. A. Geikie,¹¹⁸ after noting the differences in physical structure as well as in vegetation shown by successive portions of a bog, says that remains of trees are common. Some are embedded in soil underneath the bog; others are in the heart of the peat, proving that the trees lived on the mossy surface and finally were enclosed in the growing peat. This is illustrated by a sketch of a peat-moss in Sutherland. J. Geikie¹¹⁹ has given much information respecting the Scottish bogs but it will suffice to cite only his later work. The bogs have yielded many species of trees, all of them indigenous. The trees are *in situ*, each rooted in the kind of soil preferred by living examples. There are few acres of lowland bog in which trees have not been found. They occur even in the Hebrides, where trees now are practically unknown. Occasionally, more than one forest bed is present. At Strathcluony, three tiers of Scotch fir were seen, separated by layers of peat. Several tiers were exposed in a railway cutting across the Big Moss; one of standing fir trees with branching roots at 6 feet below the surface, a second at 12 feet and a third at 4 feet lower; so that, counting the surface growth, four different forests have existed there since the bog began.

Aher,¹²⁰ in the Bog reports, says that trees in the Irish bogs "have generally 6 or 7 feet of compact peat under their roots, which are found standing as they grew, evidently proving the formation of the peat to have been previous to the growth of the trees." On

¹¹⁸ A. Geikie, "Text-book of Geology," 3d Ed., London, 1893, pp. 478-480.

¹¹⁹ J. Geikie, "The Great Ice Age," 3d Ed., London, 1895, pp. 286-293, 303.

¹²⁰ Cited by S. S. Haldeman, in 2d Ed. of R. C. Taylor's "Statistics of Coal," Philadelphia, 1855, p. 169.

the same page Haldeman notes that it is a remarkable fact, although very common, that successive layers of trees or stumps, in erect position and furnished with their roots, are found at distinctly different levels, at small vertical distance from each other.

Grand' Eury,¹²¹ noting that the plants, active in peat-making, are not the same in all cases, maintains that a distinction must be made between peat, properly so-called, and peat of the *marais*. The former is supraaquatic, covers high plateaus and is formed chiefly by *Sphagnum*, with some other water-loving mosses. Unaccompanied by these, other plants in similar conditions give only soil. Such peat is rarely transformed into a compact *charbon* and it is obscurely stratified. The peat of *marais* is formed on low grounds, along the borders of rivers, lakes or the sea, often in extensive areas. In such places, *Arundo* grows rapidly along with *Scirpus palustris* and reeds as well as with *Hypnum*, *Nymphaea* and other semi-aquatic plants. This peat may be divided by sandy deposits and at the bottom one finds a muddy peat, almost without structure. It occurs in Holland and on the shores of the Baltic, the marshes being of great extent in both regions. Fossil peat occurs at Utnach in Switzerland.

Still different are the peats of wooded swamps and swampy forests. In depressed areas, where the forests have been killed by swamp plants, the peat, formed of herbaceous plants and prostrate stems, accumulates rapidly. He refers to the wood at Kiögge near Copenhagen, which the Danish naturalists had regarded as due to transport; but Lesquereux had shown that it is in place, the trees having been overturned by the wind—a condition observed in the present forests near by. The mass is composed almost wholly of birch and the upper part consists of empty barks entangled in a mud or half liquid paste, coming from decomposition of the wood.

Grand' Eury examined in the Ural a peat of swamp-forest origin, a mass of herbaceous plants and débris of trees. Stumps rooted in the mass were seen at two horizons in the upper part and others were scattered below. Many stems and branches lie prostrate and,

¹²¹ C. Grand' Eury, "Memoire sur la formation de la houille," *Ann. des Mines*, 8me Ser., Tome I., 1882, pp. 197-202.

at the bottom, a considerable portion is formed of barks, wood, leaves and other débris, transported and deposited in the water. Roots can be seen penetrating the gray clay on which the deposit rests. On the borders, the peat has not been changed in position and it is felted and herbaceous. In one part it seems to be composed exclusively of transported plants, there being barks of flattened birches; some laminated portions are formed of humefied epidermis material.

No reasons are given for assigning a great portion of the mass to transported material, the matter being taken apparently as beyond dispute; but one may surmise that the presence of stumps rooted in the peat, the prostrate trunks and the fragmentary condition of the enclosing material may have been for him convincing. Grand' Eury did not believe that trees would grow in peat and the fragmentary condition of plant remains was proof that they had been washed in. The conditions, described by him, are precisely those which are familiar in bogs, for which no conception of transport is admissible.

The Danish swamps were studied by Steenstrup¹²² long ago; his grouping resembles that employed by the German students. The most important is the Waldmoor or Skovmose type occupying depressions in Quaternary deposits, often more than 30 feet deep. Where the area was small, the sides were abrupt and the trees growing on them eventually fell into the bog, where they have been preserved. In depressions of great extent, one finds an exterior wooded zone surrounding an interior or central bog zone. The latter resembles the Lyngmose, the heather or Hochmoor stage.

The central area of the Skovmose is very regular. It rests on clay derived from the borders; above which one finds ordinarily one and a half to even four feet of amorphous peat, becoming pulpy in water and containing indeterminable plant remains. The peat is very pure in normal bogs, but layers of calcareous or silicious matter are not unknown. A layer of hypnum-peat rests on the amorphous deposit, 3 to 4 feet thick, containing *Pinus sylvestris*, which grew on the spot, at times forming a forest on the swamp. The trees were

¹²² Steenstrup, as summarized by Morlot, Trans. in *Ann. Rep. Smithsonian Inst.*, Washington, 1861, pp. 304 et seq.

stunted and grew slowly amid unfavorable conditions, there being 70 annual rings to the inch; yet the trees lived for several centuries. In the larger swamps, two or even three layers of pine stumps are found, *in situ*, with their bases and roots well-preserved. As the surface became higher, and drier, the earlier mosses gave place to others; *Sphagnum* appeared and, at length, heathers. The pines yielded to the birches and those to alders, hazel bushes and *Corylus*. This succession is found only in the central zone; the deposit is too thin on the border.

Weber¹²³ after prolonged study of peat areas in northern Germany, grouped the peat producing plants into (1) those which form the moor; (2) those which grow on the peat; (3) those which love peat or are bound to it. The best illustrations of the relations of these groups are in moors which began in post-glacial time and have continued until now. As the result of his examination, Weber succeeded in determining the stages in development of the bog and in determining the part played by the several groups of plants. He presented a classification which has been accepted by many of the later students. This will be given in detail as applied to the Scandinavian deposits.

Somewhat earlier, Blytt¹²⁴ had discovered that in western Norway the typical succession is

	Feet.
1. Sphagnous peat, about	5
2. Forest bed, chiefly of Scotch fir.	
3. Peat more compressed than that of No. 1, about.....	5
4. Forest bed with oak stumps and myriads of hazel nuts.	
5. Glacial deposits.	

But in eastern Norway, there are four peat layers alternating with three forest beds. In Denmark he finds equally distinct evidence for successive wet and dry periods. In summing up the conditions observed in Norway, Sweden and Denmark, he finds record of the following climatic changes:

¹²³ C. A. Weber, "Aufbau und Vegetation der Moore Norddeutschlands," *Engler. Bot. Jahrb.*, Vol. 40, 1908, *Beiblät.*, No. 90, pp. 19-34.

¹²⁴ Blytt, cited by J. Geikie, "Great Ice Age," p. 495.

1. Arctic freshwater beds, containing *Salix polaris*, *S. reticulata*, *Betula nana*, etc. A semi-continental climate.
2. Sub-glacial stage, with *Betula odorata*, *Populus tremula*, *Salix*, etc. The moors were wet, the climate humid; equivalent to the Danish "birch or aspen period."
3. Sub-Arctic stage, drier, many bogs became dry and were overspread by forest growth; Scotch fir (*Pinus sylvestris*) makes its first appearance.
4. Infra-boreal stage, climate again humid; the flora of Denmark is still of true northern type; *Pinus sylvestris* the common tree.
5. Boreal stage, climate drier and forests overspread the bogs, forming a root bed; *Corylus* and oak abundant.
6. Atlantic stage, climate mild and humid; *Quercus sessiflora* abundant, in Denmark and southern Sweden; this is the Danish "oak period."
7. Sub-boreal stage, drier than the last; many peat bogs dried up and became forested.
8. Sub-Atlantic stage, bogs again wet and the youngest peat layer was formed; this is the Danish "beech or alder period."
9. Present stage, the bogs are drying and are becoming forested.

Stages 1 to 4 are wanting in the low level bogs of the Scandinavian coast as that region was still submerged.

The peat deposits of Sweden have been studied by H. and L. von Post, Andersson, Sernander and others, and those of Finland by Andersson. It suffices for the present to present only the salient facts as recorded by L. von Post,¹²⁵ reference to the work of some others being deferred to a later portion of this work. Von Post's studies were made in the province of Narke, southern Sweden. His grouping is essentially the same as that offered by Weber but he gives details, necessary to the present discussion, not noted by other students. He finds the following types of deposits:

Limnische. I. 1. Allochthonous mineral deposits made in open water; here are clay, with diatoms, poor in plankton, and clay-gyttja, which is clay with much plankton and diatoms. 2. Allochthonous organic sediments, including (a) plankton-gyttja, in open, comparatively deep water, gray to green, more or less elastic, composed of plankton, algae abounding; (b) detritus-gyttja, in comparatively shallow water, from *Potamogeton* and *Nymphaea*, red-brown to yellow-black, granular, mostly plant débris with some plankton; (c) Schwemmtorf, composed of plant detritus; (d) Ufertorf, like the last and formed very near the line of low water. It contains lenses of Lake and of Swamp peat.

¹²⁵ L. von Post, "Stratigraphische Studien über einige Torfmoore in Narke," *Geol. Foren. Forhandl.*, Bd. 31, 1909, pp. 633-640, 644, 647.

- II. Autochthonous organic deposits. The Lake peat including (a) *Phragmites* peat, clear yellow, composed of fibrous roots with reeds and some gyttja; (b) *Equisetum* peat, like the last in structure, but the color is coal black.
- Telmatische. I. Swamp or Niedermoor peats, including (a) *Magnocarietum* peat, consisting of sedges with *Amblystegium* as accessory, yellow to yellow-brown; (b) *Amblystegium* peat, consisting of stems and leaves of that plant with some sedge constituents; (c) Bruchpeat, red to black, amorphous humefied peat detritus, *in situ*, with identifiable roots of sedges.
- II. Hochmoor peats, (a) *Cuspidatum* peat, bright colored *Sphagnum cuspidatum* and other water-loving mosses, with remains of *Scheuchzeria*, *Carex* and *Eriophorum*.
- Semi-Terrestrische. I. (b) *Vaginatum* peat, *Sphagnum* with *Eriophorum vaginatum* roots and stalks, these often making up one half of the mass, humefied and dark colored; (c) *Sphagnum* peat in lenses with *Cladina* remains between clear brown layers of *Sphagnum* with *Eriophorum*.
- II. Forest peat, (a) Alder forest peat, red-black, amorphous, consists of *in situ* deposited detritus of an alder swamp forest. Remains of alder are recognizable; *Cenococcum geophilum* abundant.
- Terrestrische. (b) Birch forest peat, like the last, but commonly dark colored, deposited in a birch swamp forest; (c) Forest peat, rich in *Eriophorum* and *Sphagnum*, as a rule, dark colored, almost always with stumps and other remains of Scotch fir; (d) Forest mould, dark, composed of wood detritus and grains of humus, with stumps.

All of these types from Lake peat down are autochthonous. The upper limit of the basin or limnic deposits is at the normal line of low water; the shore or telmatic deposits are in the space covered at high water, while the terrestrial are on forested areas, rarely covered with water. The alder swamp is the passage zone to the terrestrial. Von Post confirms Blytt's conclusions respecting the alternation of dry and humid periods, and shows how, during the less humid times, forests invaded the peat deposits and in some cases covered the surface of pure peat with a dense growth. He presents sections from a number of localities. One from the Åsta moor shows

- A. *Sphagnum* peat, 85 centimeters, with, at 80 centimeters, a mass of fir stumps rooted in the peat and with coaly matter between the stumps.
- B. Strongly humefied *cuspidatum* peat, 10 centimeters.
- C. Sedge peat, 30 centimeters, has much *Sphagnum* above.
- D. Alder and birch swamp forest peat, with small stumps of alder, birch willow and a great quantity of *Cenococcum geophilum*, 15 centimeters.

E. Shore peat, like transported peat, 25 centimeters, roots of *Carex*, *Equisetum* and *Phragmites*.

F. Plankton-gyttja, 40 cm. with remains of infloated *Phragmites*, *Equisetum*, etc., some pollen of *Picea* in upper portion.

G. Clay, 50 cm. rich in saltwater diatoms.

As interpreted by Von Post, one has here at the bottom, a deposit of plankton material or Sapropel. It was invaded by the shore peat, on which a forest of birch and alder grew for a short time amid unfavorable conditions, as the swamp was overflowed at times; this condition became more marked and a sedge swamp followed, in which *Sphagnum* gradually gained control. Still later, for a short period, during which accumulation of peat continued unchecked, the moor was covered with a dense growth of firs; but as the moisture increased, the non-water-loving elements disappeared and a *Calluna-Eriophorum* moor occupied the area. Sections in Skarby lake complex show the same general features as those observed elsewhere in this region. Though there are differences in detail, the story is practically the same throughout. The open water deposits, gyttjas rich in plankton material, form the lowest stratum resting on clay or sand; on this is the shore peat, which gradually passed across the basin. Then came the time of decreasing moisture; alders advanced on the peat surface, now subject to only occasional overflows; they were succeeded by birches, which were rooted in the alder peat; and finally came the great forests of Scotch fir growing in the birch and alder peat, to be succeeded by *Sphagnum*-Hochmoor peat in the moist Sub-Atlantic stage. Peat-making was continuous in the forests and each type of forest peat has its own group of minor plants.

Buried Peat Deposits.—Some authors have contended that peat deposits on the land are not likely to be preserved because, exposed to air, they must be affected by atmospheric conditions and eventually must waste away. Under such conditions, it is certain that only such accumulations of vegetable material as are deposited in water-filled basins would be preserved. But the supposed conditions are purely hypothetical and are not in accord with those existing in nature. Indeed, one looking at a peat deposit, many feet thick, would have difficulty in conceiving how there could be uniformity of conditions for a period long enough to permit wastage

of so great a mass, almost impermeable to water after having become thoroughly air-dried. But *a priori* reasoning is unnecessary; for, as Lesquereux recognized long ago, burial of peat bogs is part of the normal sequence of events.

Dawson¹²⁶ has described an early Quaternary bog which he saw in Nova Scotia. It underlies 20 feet of boulder clay and pressure has made the peat almost as hard as coal, though it is tougher and more earthy than good coal. When rubbed or scratched with a knife, it becomes glossy; it burns with considerable flame and approaches the brown coals or poorer varieties of bituminous coal. It contains many roots and branches of trees apparently related to spruce.

Areas of peat buried under glacial drift are numerous in the New England states as well as in New Jersey and some of them will be mentioned in a succeeding section. Newberry,¹²⁷ many years ago, collected all the observations then available for states west from the Alleghany mountains. In Montgomery county of Ohio, E. Orton found a bed of peat, 15 to 20 feet thick, the surface covered with *Sphagnum*, grasses and sedges. It contains coniferous wood with bones of elephant, mastodon and teeth of giant beaver; and it underlies 90 feet of gravel and sand. At many places in Highland county of the same state, wells have reached a stratum of vegetable matter and, at Cleveland, a "carbonaceous stratum" has been found at 20 feet below the surface. A similar condition exists at Lawrenceburg, Indiana, as well as at many places along the Ohio; and J. Collett reported that, throughout southwestern Indiana, there is an ancient soil, 2 to 20 feet thick, with peat, muck, rooted stumps, branches and leaves, at 60 to 120 feet below the surface. This deposit is known locally as "Noah's cattle yards." The same condition is reported from a portion of Illinois. The great forest bed of Iowa, discovered by McGee at a later time, is in part a buried bog. Leverett, Taylor, and Goldthwait have described autochthonous peat bogs buried under glacial drift at many localities within the Mississippi area.

¹²⁶ J. W. Dawson, "Acadian Geology," 2d Ed., London, 1868, p. 63.

¹²⁷ J. S. Newberry, "Surface Geology of Ohio," Geol. Survey of Ohio, 1874, Vol. II., pp. 30-32.

In America, observations as recorded are very few and, for the most part, they are merely incidental, as until very recently the geological importance of peat was not recognized; but in Europe the case is very different; one finds there such a wealth of illustration as to cause surprise that any student should entertain doubts respecting preservation of peat deposits by burial under sediments. A few citations must suffice.

J. Geikie¹²⁸ says that peat bogs often pass below the sea. In the harbor of Aberdeen, trunks of oak are brought up and at a little distance away, peat was seen below the sea level covered with 10 to 12 feet of sand. This bed, enclosing trees, is known to extend for some distance into the bay. In the Carse lands, the river Tay has cut down to a peat bog, now forming the river bed and underlying about 17 feet of alluvial material, which near the top contains cockles, mussels and other marine forms. This extensive peat deposit of the wide Carse area rests in part on alluvial sands and in part on marine clays. The peat is highly compressed and splits readily into laminæ, on whose surfaces are small seeds and wing cases of insects. As a rule, but not always, it is marked off sharply from the overlying clay and silt. That it represents an old land surface is certain but it is equally clear that, in great part, the vegetable débris on top was drifted in from localities higher up in the valley, for the upper part of the peat contains, at times, layers of silt and twigs, while branches as well as trunks are scattered through the lower 3 or 4 feet of the overlying silt. The conditions are the same in Carse lands on both sides of Scotland and they exist in the Hebrides.

Prevost and Reade¹²⁹ have described a peat bed covered by a thick deposit of sediments. The exposed portion is a dark-brown peaty mass, containing large and small branches, roots and rootlets, the latter passing into the underclay. Some large boles and an occasional stump were seen on the upper surface. The authors note as a remarkable fact, that this bed resists erosive action by the river

¹²⁸ J. Geikie, "The Great Ice Age," 1895, pp. 290-293.

¹²⁹ E. W. Prevost and T. M. Reade, "The Peat and Forest Bed at Westbury-on-Severn," *Proc. Cotteswold Nat. Club*, Vol. XIV., 1901.

as well as by the more energetic bore, so that it projects as a promontory. Strahan¹⁸⁰ measured the section exposed during excavations for docks on Barry island. The succession is

1. Blown sand, *Scrobicularia* clay, sand, shingle, with strong line of erosion below. 2. Blue silt with many sedges. 3. Upper peat bed, 1 to 2 feet thick. 4. Blue silty clay with many sedges. 5. Second peat bed, thin. 6. Blue silty clay with sedges. 7. Third peat bed, with many logs and stools, roots in place underneath. 8. Blue silty clays with reeds, willow leaves and freshwater shells. 9. Fourth peat bed with large trees and roots in place and numerous land shells. 10. An old soil with roots and land shells. 11. Rock in place, at 35 feet below the Ordnance datum.

Here as in the Carse area of Scotland, the peat underlies a deposit containing marine shells.

Lesquereux¹⁸¹ cites a French author, who found at many places in the Department of Nord alternations of peat and sand, the latter containing marine shells. He notes that when the growth of peat is checked by dryness, a crust forms, which is a parting between the old and the new peat. In the valley of the Somme, he found, underlying 8 feet of clay and concretionary limestone, 23 feet, 4 inches of peat in 15 layers, with the partings distinct and the layers differing in character. Alternations of clay, peat and calcareous concretions are not rare.

Geinitz,¹⁸² more than twenty-five years ago, studied the dune-covered bogs near Rostock. At a later period he had opportunity for more detailed examination and his observations are important from several points of view. At the bathing station near Graal, the section shows at the bottom, sand of the Rostock plain, on which rests a one-foot layer of peat, containing stumps of trees which grew on it. The dune formerly covering this deposit has been removed for some distance, exposing the peat, but it still remains at a little way landward. Beyond the dune, one finds a forest of great beeches and oaks, with the peat bed covering the surface between them.

¹⁸⁰ A. Strahan, Mem. Geol. Survey, "Geology of the South Wales Coal Field," Part III., 1902, pp. 87-93.

¹⁸¹ L. Lesquereux, Ann. Rep. 2d Geol. Survey of Penn. for 1885, pp. 116-118.

¹⁸² E. Geinitz, "Nach der Sturmflut," *Aus der Natur*, Vol. IX., 1908, pp. 76-83.

When he looks at the dune surface, he sees, as it were, shrubs rising out of the sand, some short thick stems of beech and oak; but they are not shrubs, they are the still living parts of trees, the same in age and growth as those standing in the open forest. They have been buried by the advancing dune. A mighty storm flood, tearing away the sea wall and removing part of the dune, will expose vertical trees standing in the sands as in the Coal Measures sandstones. At present, one sees advancing masses of sand burying the trees, which grow on low-lying moors. At another locality, storms, during recent years, have exposed an older peat deposit, underlying the sands of the Rostock plain. The outcrop extends hundreds of meters along the shore and shows that the peat is a moss peat, which bore a forest of Scotch fir. There, as also near Graal, the waves have torn off fragments of the peat and have worn them down into elliptical form similar to that of the beach pebbles. Barrois¹³³ has referred to similar origin of peat pebbles on the shore of the British channel, where some neolithic deposits of peat are exposed to the waves. The fragments of peat are rolled, rounded and eventually transformed into true ellipsoidal pebbles.

Lorie,¹³⁴ in his fifth contribution to the surface geology of Holland has gathered together all the available information respecting the buried recent peat deposits of that region.

In all probability the Zuyder Zee was filled with peat prior to the catastrophe of the middle ages, but the only vestige is on the island of Schalkland, where one finds 5 to 7 meters of peat covered with a meter or more of marine clay. The same condition exists on the river Y near Amsterdam and in the province of Zeeland as well as in the west part of North Brabant in Belgium. The peat bed near Oudenbosch, in the latter province, is 0.75 meter thick and underlies 0.65 meter of sediment. It is readily traceable from that village across Zeeland into western Flanders of Belgium, and thence to the coast at Ostend in Belgium and Dunkerque in France, a dis-

¹³³ C. Barrois, "Observations sur les galets de cannel-coal du terrain houiller de Bruay," *Ann. Soc. Geol. du Nord.*, Vol. XXXVII., 1908, p. 7.

¹³⁴ J. Lorie, "Les dunes intérieures, les tourbières basses et les oscillations du sol," *Archives Mus. Teyler*, 2me Ser., Vol. III., 1890, pp. 424-427, 444, Pl. 2.

tance of more than 60 miles. Lorie cites Belpaire père, who says that it is one to 3 or even 4.5 meters thick and that it rests mostly on blue clay, though in some localities on fine sand. It is double near Ostend, where the lower bed is black, compact, with roots of reeds, while the upper bed contains no reeds but has woody fibers, apparently roots of heath plants. The peat and its overlying clay are sometimes continuous under the dunes and shore, as is also the case on the island of Walcheren in Zeeland. Trees, rooted in the subsoil, occur frequently in the peat. Belpaire fils says that the thickness of the peat and that of the overlying clay vary from 1 to 3 meters and that the clay level is never above high tide. On the left bank of the Escaut (Scheldt) as it flows from France across Belgium the peat is almost a meter and a half thick, but the clay, 2 to 3 meters, decreases as it recedes from the river. Lorie says that Rutot found a divided peat near Blankenberghe in Belgium. Reference to Rutot's¹⁸⁸ publication shows that the section is

	Meters.
1. Shore sand	2.30
2. Gray sandy clay	0.60
3. Gray sand, with bed of <i>Cardium</i> midway	1.10
4. Pure peat	2.00
5. Gray sand, slightly argillaceous	0.40
6. Sandy clay	0.50
7. Gray, argillaceous sand	2.50

The peat underlies a marine sand and overlies a sand which is but slightly argillaceous.

In 1852, Harting, as cited by Lorie, discovered hard dry peat at 10 to 12 meters below the surface in Amsterdam. Ghyben followed this eastward toward the Wecht river. For much of the distance, it is covered with marine sand, but at that river it is covered with the main mass of peat, constituting the boundary between the sandy diluvium and the alluvial deposits. In later years it became possible to confirm and to extend the early observations, for many borings have been made along railroad lines within the polder areas of Holland. Lorie has tabulated the records of 124 such borings, showing

¹⁸⁸ A. Rutot, "Le puits artésien de Blankenberghe," *Bull. Soc. Belge de Geol.*, Vol. II., 1888, *Mem.*, p. 261. This author has given equally illustrative records in later memoirs published in this *Bulletin*, Vol. VIII., 1894; Vol. XI., 1897.

the conditions between Enkhuizen, north from Amsterdam, and Dordrecht, south from Rotterdam, as well as in localities east and west from that line. It is unnecessary to give more than a few of these as in any group the same conditions are found. Eighteen borings are reported along the east and west line from Rotterdam to the Hook of Holland. Seven of these follow, the measurements being in meters and the numbers are those of the records:

	85.	87.	88.	89.	90.	92.	102.
1. Sand and clay.....	4.5	3.9	3.2	6.0	5.1	2.5	4.5
2. Peat	0.9	1.4	3.0	1.5	2.6	4.5	3.2
3. Sand and clay.....	..	..	..	..	0.5	5.5	2.5
4. Peat	..	..	..	..	0.3	1.0	0.5
5. Sand and clay	..	..	..	..	6.0	..	0.1
6. Peat	..	..	..	..	1.0	..	0.5
7. Sand and clay	..	..	..	..	..	..	1.5
8. Peat	..	..	..	..	..	..	1.0
9. Sand and clay	..	..	..	..	..	..	1.2
10. Peat	..	..	..	..	..	..	1.0

These exhibit the variations to a depth of 16 meters. The material in each case below the lowest peat bed in the column is sedimentary clay and sand. Peat was found in some localities at 19 meters, but it is never continuous to that depth, being always divided by sediments. The greatest continuous thickness found in any boring is 10 meters. At times the peat is replaced wholly by sediment and one can trace old river courses in which no peat was formed and which now are filled with the transported sediment. The records show the conditions in an area of 70 by 20 miles, throughout which one finds one or more beds of peat covered with a greater or less thickness of sediment. These are autochthonous, and they contain stems of trees rooted in the subsoil. The intervening deposits are often distinctly marine in many parts of Holland; a section by Lorie shows

	Meters.
1. Peat	3.2
2. Gray clay, sandy below, calcareous, marine diatoms below, plant remains in upper part	0.8
3. Argillaceous sand with <i>Cardium</i> and <i>Scrobicularia</i>	5.9
4. Black peat	0.5
5. Tough grayish blue clay	1.1
6. Black, hardly coherent peat	1.2

The portion of Holland considered in Lorie's tabulated records is not less than 1,500 square miles; a more extensive area in Belgium shows the existence of covered peat deposits and this condition reaches far over into France, for, at Cotentin in Normandy, the peat, 20 meters thick, is covered with 3 meters of marine sand. One has in this region an area, almost as great as that of the Everglades in Florida, in which the existence of buried peat bogs has been proved, some of them having been traced continuously in a great part of the region. How great the total area may be, has not been ascertained, but it is very much greater than that which has been studied in detail.

The change in structure and composition of peat, as the depth increases, has been referred to more than once in the preceding pages. Evidently the older the peat, other things being equal, the more thoroughly the material is disintegrated. If compacted by pressure and the removal of water, it assumes the appearance of brown coal and does not regain plasticity, as appears from the descriptions by Dawson and Lesquereux, to which many others might have been added. It is certain that some constituent, once soluble in water, has become insoluble, as soluble silica, once dried, becomes insoluble. When the deposit, exclusive of enclosed wood, has been reduced to mature peat, one must resort to chemical reagents and to the microscope in order to ascertain the component materials. Those bring to view a structure, a physical composition, which is wholly similar to that which Grand' Eury gives for coal studied after the same method. It is a mass of disintegrated fragments, held together by a fundamental material, much of which was originally flocculent. The older quaternary peats show much variation; that described by Dawson has little which suggests peat to the unaided eye; but there are others which so much resemble the newer peats that, were it not for the presence of extinct mammals and the great thickness of cover, one might hesitate before deciding that they are not of recent origin. There are still others, which in the several layers exhibit great variations, some being of comparatively unchanged peat, while the material in others has lost all of the original macroscopic features.

Among the latter group, the most noteworthy example is the Schieferkohle of Utnach, Dürnten and neighboring localities in Switzerland, which is interesting from the economic as well as the scientific point of view. Having been studied in great detail by several geologists, it will suffice as type. Some have thought that these deposits are post-glacial, in which case, they would possess the greatest possible interest to students seeking to ascertain the mode in which vegetable matter became converted into coal and gathered into beds. But the age remains unsettled; Heim¹⁸⁶ maintains that the Schieferkohle lies between moraines. The section in detail at Wetzikon and Utnach shows drumlines and erratic blocks of the last glaciation resting on fluvio-glacial gravels. The lignite, underlying the latter, 1 to 3 meters thick, rests on boulder clay of the greatest glaciation. These lignites are autochthonous, full of *Betula alba*, the stems at times vertical and with their roots in the underlying boulder clay.

Heer¹⁸⁷ in his earlier work discussed the Utnach and Dürnten deposits, but dwelt more in detail on the latter as, at that time, it was the better exposed. The lignite is 12 feet thick, rests on clay and underlies about 30 feet of sand and gravel. It is not continuous vertically, but is divided by 6 clay partings, in all about 2 feet. The lowest bench contains much wood together with cones of *Pinus abies*, which are not found in the upper benches. In each higher bench, one finds at the bottom, whole layers of mosses, felted together and pierced by reeds, while above are stems, lying in all directions, with roots, barks and fragments of wood, all pressed flat. The annual rings are distinct in many stems and in one Heer counted 100. Some coaled stems were seen, which he thinks may have been charred by lightning. The trunks are surrounded as in peat by a black-brown mass, which undoubtedly originated from decay of herbaceous plants, converting them into a pulp-like mass. This succession is repeated in every branch, but, in the topmost, stems are comparatively rare, mosses and reeds predominating.

¹⁸⁶ A. Heim in letter of May 23, 1911.

¹⁸⁷ O. Heer, "Die Schieferkohlen von Utnach und Dürnten," Zurich, 1858, pp. 7-11; "The Primeval World of Switzerland," *Eng. Trans.*, London, 1876, Vol. I., pp. 29, 30, 32; Vol. II., pp. 149-155, 157, 161-163.

The plants and the conditions are those of a peat moor. The mosses belong to the peat-forming group; the reeds and sedges are swamp plants to which also belongs the bogbean (*Menyanthes*) of which the seeds are abundant in both the coal and the partings. Spruce is present only in the lowest bench but birch and fir (*Pinus sylvestris*) are in the higher benches. The trees are those of the swamps. The animal remains belong in part to a swamp fauna, there being great abundance of insect wing-cases on surfaces of the peat and clay layers, while with them are shells of freshwater mollusks. The larger animals are mammals. Everything goes to show that this Schieferkohle is a compressed, dried out peat and the older opinion—that it originated from drifted wood—is incorrect.

In his later work, Heer gives additional facts respecting Dürnten and some noteworthy observations concerning other localities. At Dürnten, a wedge of sand and pebbles separates the main mass from a 6-inch layer of peat and stems above. The main portion is horizontal, while the thin layer dips toward the place of union and the sands overlying it have the same dip. At Unterwetzikon the lignite, underlying 12 to 30 feet of stratified sands and gravel, rests on a marl with freshwater shells. At Utznach, there are two beds, 5 and 3 feet, separated by 16 to 20 feet of light colored marly material, and the lignite retains its original horizontal position. At Morschwyl, the lignite is 2 feet thick, with vertical tree stems, the whole marly deposit, including the lignite, being 8 feet thick and underlying 26 feet of detritus. At another locality, the cover is 70 feet and the deposit is 3 feet, with vertical stems, 6 feet high and 3 feet diameter, extending into the marl above. This lignite underlies and overlies marl, the whole mass being about 16 feet thick. Heer gives a list of the plants recognized at the several localities and discusses their relations, showing that the grouping is clearly that observed in peat bogs of northern Europe.

v. Gümbel¹⁸⁸ studied this Schieferkohle from many places in Switzerland and southern Bavaria, his typical locality being Morschwyl. In both the partly loose peat-like and the partly dense pitchcoal-like portions, numerous horizontal-lying fragments of

¹⁸⁸ C. W. v. Gümbel, "Beiträge zur Kenntniss," etc., pp. 135-138.

boughs and stems were found, mostly conifers, birches, willows and alders, which in some cases resemble brown coal, in others, pitch coal. The peat-like character of the whole mass, as described by v. Gümbel, recalls the buried bogs of Ohio and Indiana. Treated with caustic potash, the looser portions become a soft, dense felted mass, in which the microscope detects as prevailing constituents, leaves of grasses with mosses. *Sphagnum* is the prevailing form. Fragments of wood are comparatively rare, though needles and twigs of conifers are not wanting. The denser portions need application of Schultze's test, a mixture of potassium chlorate and strong nitric acid, which must be allowed to act for a considerable time in order to separate the plant remains. These are the same as in the looser portions. But in addition are splinters of a deep brown structureless material, behaving as dopplerite. It fills cell-spaces in many plant-fragments; this textureless material is the Carbohummin. The numerous cones embedded in the mass are not deformed.

In passing from the Quaternary to the Tertiary, one finds increased difficulty in recognizing peat bogs; the conditions, observed in the older portions of recent bogs and in those of the Quaternary, are intensified by compression and by removal of the water, which kept in soluble condition the ulmic and humic constituents, while advancing chemical change has converted the whole mass into the mature condition. In fine, the amorphous plastic peat has become amorphous brown coal and only trunks of resistant wood remain to tell the story. Yet in some cases the resemblance is so great that little room remains for doubt. A typical instance is the great Senftenberg Miocene deposit, described by Potonié, to which reference will be made again on a succeeding page. To one familiar with the cypress swamps of the United States, there can be no question respecting the origin of that deposit. Aside from loss in plasticity of the peat, and its conversion into brown coal, the description given by Potonié would apply equally well to the white cedar swamps of New Jersey or to some of the *Taxodium* swamps of the Mississippi, where the peat is equally pure, the mud and silt having been strained out as the water passed through cane brakes.

Heer, in his "Primeval World of Switzerland," says that at

Dürnten, the Schieferkohle rests on a gray-white marl containing *Anodonta*, *Valvata* and *Pisidium*. That marly clay rests on the Oligocene Molasse, which holds a bed of lignite. The woody limbs are still distinct but the rest of the mass has been changed beyond recognition. Yet one finds traces of marsh plants in the overlying marls, while underlying the lignite is an undoubted lake-marl containing *Unio*, *Planorbis* and *Lymnaea*.

Conclusions.—In this presentation of the features characterizing peat deposits, some facts appear in notably bold relief.

1. Peat deposits vary in form from lenses to sheets; the former are of petty to considerable extent, fill depressions such as pond or small lake basins; the latter, often of vast extent, originate on approximately level areas, where drainage is imperfect. The bottom and top are apt to be irregular; the latter because of islands or sandy deposits but especially because of streams and shallow ponds; but the form of the bottom depends on that of the surface on which it rests. The thickness may show great variation; a few inches of peat at one locality may be continuous with a deposit, 10 or even 60 feet thick elsewhere. Great deposits are not continuous vertically; partings divide the bed into benches; those partings may be very thin, clay or sandy clay with much woody matter, merely desiccated peat wasted by exposure during a dry period, or they may be sediments, varying from films of clay to beds of sand, gravel or clay, loose or consolidated. Peat deposits, especially those of great horizontal extent, often bifurcate and, at times, the "splits" reunite. The underlying material may be clay or sand—usually clay or marl for the lens-shaped deposits, but very often sand or sandy clay for sheet deposits extending over great areas. Sand with slight admixture of clay becomes practically impermeable by absorption of humic acid.

2. Peat deposits are recognized by macroscopic features as far back as the middle Tertiary. Some of Post-glacial age and several thousands of miles in extent are buried under 3 to 30 feet of sediment; some Quaternary deposits underlie 30 to 120 feet of transported inorganic matter and the overlying deposits vary from fine

clay with plant impressions to fine or coarse sandstone, conglomerate or even breccia.

3. Many vast moors, such as those of the Netherlands and North Germany as well as great and small moors in the United States and elsewhere, are at only a few feet above tide. A very slight depression suffices to bring the surface below that level and to introduce marine conditions. In lowland areas, thousands of square miles in extent, one finds a marine deposit, with characteristic fossils, immediately overlying peat, which is sometimes continuous with a still living moor above high tide. In such areas, one finds occasionally a marine deposit, clay or sand, immediately underlying the peat. The overlying or the underlying material or both of them may be distinctly calcareous.

4. The passage from peat to the overlying deposit may be abrupt or it may be gradual through alternations of peat and sediment.

5. The channel ways of streams crossing the moors are traceable in borings after the moors have been covered with sediment; they contain little or no peat.

6. The peat deposit is not always homogeneous. Sapropel, organic mud, is the foundation in a great proportion of lake deposits in Europe and in some within the United States; it is probably absent at bottom of great sheet deposits; but it may occur as lenses in any part of the section, marking the sites of shallow ponds. Sapropel is an unimportant constituent of true peat, which is produced by water-loving land plants, the work of other types being a negligible factor. The several benches of a deposit may differ notably in structure and composition. Peats are laminated even when new, but under compression, the lamination is characteristic and the material has a coal-like appearance.

7. Peat varies greatly in purity. At times, it has less ash than is found in plants whence it is derived, owing to the action of organic acids on silica and other mineral constituents; in most cases it shows notable variations, both vertically and horizontally, that variation depending chiefly on extent of exposure to flooding by muddy waters. Peat often contains a considerable quantity of iron and calcium in combination with carbonic, sulphuric and phosphoric

acids. Alumina and sodium chloride seem to always be present, though the latter is in small proportion.

8. When mature, peat consists of minute fragments of plants, embedded in an amorphous substance, more or less flocculent, the whole cemented by an originally soluble substance, which fills clefts in the peat and at times clefts in the underlying deposit and, in the older peat, penetrates even the cell tissue of plant fragments.

9. In a very great number of peat deposits, one finds erect stems of trees, rooted in the underlying clay or sand. Within extensive areas, the peat mass is crowded with successive generations of trees, which had grown on the peat, their roots not penetrating to the soil below. In the case of the less durable woods, the interior has disappeared and the compressed bark remains; but the prostrated stems of the more durable or resinous woods have resisted decay and they have retained their form; yet in Quaternary peat, the flattening is more or less marked in all. Peat is not good soil for all kinds of plants even when dry, but, even when wet, it is the soil on which several types of majestic trees thrive best; when somewhat less wet, it is the habitat of some other great trees, which flourish, while peat accumulates around their stems.

10. Peat accumulates within the tropics wherever conditions of topography and humidity are favorable.

11. The deposits of true peat are autochthonous.

BURIED FORESTS.

Long ago, erect trees with roots and at times with branches attached, were observed in the Coal Measures. Some geologists were convinced that the existence of these trees was proof that coal beds were formed *in situ*. The force of this argument seems to be recognized by some of those who favor the doctrine of origin by transport, for, in later years, every reported discovery of trees or forest buried *in situ* has been met with incredulity or worse. The writer does not share in the opinion that the presence of trees buried *in loco natali* is of serious import as an argument, directly, either for or against any hypothesis respecting the mode of coal bed formation; but, in this, he apparently differs from so many geologists,

that it may be well to supplement the references to buried swamps by some notes upon buried forests.

Russell's¹³⁹ description of conditions on the Yahtse river of Alaska relates that the stream, issuing as a swift current from beneath the glacier, has invaded a forest at the east and has surrounded the trees with sand and gravel to a depth of many feet. Some of the dead trunks, still retaining their branches, project above the mass, but the greater part of them have been broken off and buried in the deposit. Other streams, east from the Yahtse, have invaded forests, as is indicated by dead trees standing along their borders. Where the deposit is deepest, the trees have already disappeared and the forest has been replaced with sand flats. The decaying trunks are broken off by the wind and are buried in prostrate position. This deposit, consolidated, would resemble closely a Coal Measures conglomerate.

The submerged forest on the Columbia river of Oregon was observed first by Lewis and Clark and it was examined almost 30 years afterwards by Wilkes; but Newberry¹⁴⁰ was the first to study it in detail. He found the river bordered at intervals on each side by the erect but partially decayed stumps of trees, which project in considerable numbers above the surface of the water. These stumps belong to the Douglas spruce, which still covers the mountain slopes. The dam at the Cascades is a conglomerate, penetrated by threads of silica, often filling cavities with agate and chalcedony. It contains many trunks of trees, some of them merely carbonized, others silicified, while still others show both conditions. These trunks have a microscopic structure closely resembling that of the Douglas spruce. The writer may add that similar conditions exist in the buried forest near Salem on the Willamette river in the same state.

Along the whole Atlantic coast from Nova Scotia to Florida, one finds sunken forests now buried under peat or sediments. Dawson described one seen on the coast of Nova Scotia at 25 to 30 feet below high tide, where the stumps were rooted in material, having

¹³⁹ I. C. Russell, "Second Expedition to Mount St. Elias," Thirteenth Ann. Rep. U. S. Geol. Survey, 1893. Pt. I., p. 14, Pl. XII.

¹⁴⁰ J. S. Newberry, Pacific Railroad Explorations, Vol. VI., 1856, "Geological Report," p. 56.

all the characteristics of a forest soil, and were scattered irregularly as in an open wood. E. Hitchcock asserted that buried forests are numerous along the coast of Massachusetts; cedar, oak, maple and beech trees are found in the harbor of Nantucket, some erect, others prostrate and all of them surrounded by an imperfect peat. This forest is buried under 4 feet of sand. Cook¹⁴¹ has described many buried forests in New Jersey, the most interesting being those now concealed under the tidal marshes. At one locality, a ditch was dug to drain some large tidal ponds; it exposed nothing but mud and grass roots; the outrush of water at ebb tide widened this narrow drain to 70 feet and scoured the bottom, which proved to be thickly set with pine, white cedar and gum stumps, standing upright and giving every indication that they were where they had grown.

Tuomey¹⁴² has described an area of tidal marsh, which is covered with live-oak trees, some standing, but most of them prostrate. These are certainly not where they grew and it is equally evident that they have not been transported. Originally, this mud flat, now littered with shells of oysters and mussels, was covered with sand hills, of which some remain. During storms, waves broke over the peninsula, washed away the sand hills and left the trees, some of which remain standing because supported by their broad roots. At another locality, a great white cedar swamp shows living trees, but, toward the river, the trees are dead and the continuation of the mass under the river shows stumps in place. Encroachment of salt water killed the dense undergrowth of the swamp—decomposition of the exposed peat advanced and the trees broke off at the "air line." He refers to many places where the saltwater invasion and subsequent change in the swamp material caused destruction of the white cedar or cypress forest; sediment covered the stumps and another growth followed.

Agassiz,¹⁴³ observed a submerged forest at the mouth of the Igurapi Grande, which clearly belongs to the recent epoch.

¹⁴¹ G. H. Cook, "Geology of New Jersey," 1868, pp. 350, 352, 354, 355, 360.

¹⁴² M. Tuomey, "Report on the Geology of South Carolina," Columbia, 1848, pp. 194-200.

¹⁴³ L. Agassiz, in "A Journey to Brazil," Boston, 1868, pp. 434, 435.

"Evidently this forest grew on one of those marshy lands constantly inundated, for between the stumps is accumulated the loose felt-like peat characteristic of such grounds and containing about as much mud as vegetable matter. Such a marshy forest, with the stumps of the trees still standing erect on the peat, has been laid bare on both sides of the Igurapi Grande by the encroachments of the ocean. That this is the work of the sea is undeniable, for all the little depressions and indentations of the peat are filled with sea sand and a ridge of tidal sand divides it from the forest still standing beyond. Nor is this all. At Vigia, immediately opposite to Souré, on the continental side of the Para river, just where it meets the sea, we have the counterpart of this submerged forest. Another peat bog, with the stumps of innumerable trees standing in it and encroached upon in the same way by tidal sand, is exposed here also."

Forests buried during the recent epoch are such familiar and commonplace features that further reference to them is unnecessary.

Forest beds of Quaternary age have been reported by observers in many parts of the world. Reference has been made already to the great forest bed of southwestern Indiana, buried under 60 to 120 feet of later glacial material. McGee¹⁴⁴ has described a forest bed, which divides the glacial deposits in northeastern Iowa. It was much disturbed during a later advance of the ice. Accumulations of logs, stems, grasses and peaty soils occur at many horizons in both the upper and the lower till, but they are in largest volume and least disturbed condition at the junction of the two drift sheets. The distribution is related to that of the upper till. Where the glaciation was most energetic, the deposit is absent; where less energetic, it is present but broken up badly; toward the eastern part of the area, the disturbance decreases and the deposit is found in normal condition with everything *in situ*. There one finds the peaty soil with stumps and roots all evidently in place.

Quaternary forest beds are many in Europe. It suffices to quote from J. Geikie,¹⁴⁵ who has described the condition in Great Britain.

"The broad facts then are these: at a depth from the surface, varying from 20 to 60 or 70 feet, occurs a layer of peaty matter enclosing and covering forest trees, the stools of which are often rooted in an ancient soil. Above this buried land surface appear lacustrine, or estuarine or, as

¹⁴⁴W J McGee, "The Pleistocene History of Northeastern Iowa," Eleventh Ann. Rep. U. S. Geol. Survey, 1891, Pt. I., pp. 199-577. Citations from pp. 486-496.

¹⁴⁵J. Geikie, "The Great Ice Age," 3d Ed., p. 405.

the case may be, marine deposits. Next comes a second forest layer, overlaid by similar accumulations. It is the second forest bed, which is so frequently exposed upon the present fore shores."

In succeeding pages this author gives detailed evidence respecting the stratigraphic relations of forest beds at the different localities.

Passing from the Quaternary to the Tertiary, one finds less frequent notices of buried forests, owing, of course, to lack of exposures. Lyell,¹⁴⁶ after describing the buried cypress swamps of the Mississippi delta, mentions the Tertiary deposits at Port Hudson, which had been seen by Bartram and, at a later date, described by Carpenter. Bartram observed that the erect cypress stumps seemed to be rotted off at 2 or 3 feet above the spread of the roots and that their trunks, limbs, etc., lie in all directions about them. When Lyell visited the locality, the water was too high to permit study of the lowest part of the section and he gave Carpenter's statements respecting it. At the bottom of the bluff, is a buried cypress swamp, containing sticks, leaves and fruits in horizontal laminæ, with filmy layers of clay interposed. With these are great numbers of erect stumps of the large cypress, sending roots into the clay below. At 12 feet higher is a second deposit, 4 feet thick, consisting of logs and branches, half converted into lignite, along with erect stumps. Above this are more than 50 feet of clays, containing two layers of vegetable matter.

Hilgard¹⁴⁷ gives some details respecting what is evidently the lower Port Hudson bed as seen between that place and Fontania. The section in the bluff is

	Feet.
1. Yellow loam	8 to 10
2. White and yellow hardpan	18
3. Orange and yellow sand	8 to 15
4. Greenish or bluish clay	7
5. White silt or hardpan	18
6. Green clay with calcareous and ferruginous concretions, sticks and leaf impresions	30
7. Brown muck or blue clay with cypress stumps	3 to 4

¹⁴⁶ C. Lyell, "A Second Visit to the United States," etc., Vol. II., pp. 134, 178, 179, 180, 192, 272, 273.

¹⁴⁷ E. W. Hilgard, "On the Geology of Lower Louisiana," Smithson. Contrib. No. 248, 1872, pp. 5-7, 9, 11.

"These stumps evidently represent three or four successive generations, growing at higher levels as the surface of the swamp was raised by deposition." Some of them are large and the wood is so hard that it is difficult to detach a piece with the hatchet. No. 5, in some places, is a river alluvium and at times resembles a sandbar. It frequently contains great quantities of driftwood.

The cypress stumps in No. 7 are well preserved and hard, but the driftwood in No. 5 is soft and spongy. When water-soaked and resting on the ground it is visibly flattened by its own weight; one stroke with the hatchet will sever a trunk, 20 inches or more in diameter. But if this soaked material be exposed to continuous sunshine, it not only loses water but also contracts into hard shining lignite, with conchoidal fracture and exhibiting to the eye scarcely a trace of the original structure. A trunk, 6 or 8 inches in diameter, when thus dried, forms a contorted coal layer not more than half an inch thick. The exposed portion of a trunk may be transformed in this way, while the portion, remaining embedded, retains the original features. These changes are very like those seen in the lignite at Putznach as described by Bischof; there is evidently a change from soluble to insoluble in some constituent of the trunk. Hilgard¹⁴⁸ had traced the deposit underlying the Orange sands through a great area in southern Mississippi and the features seem to be the same throughout. It "cannot be better described than as the soil of a cypress swamp, with its muck, fallen trunks, stumps, roots and knees. Of these there are evidently several generations, separated by more clayey layers of muck."

Eldridge¹⁴⁹ mentions a deposit of Eocene lignite in Alaska containing 10 to 15 beds varying in thickness from 6 inches to 6 feet. The ash is from 1.85 to 10.68 per cent. The lignite of these beds resembles a mass of carbonized wood. Stumps, 1 to 2 feet in diameter, are common, standing vertical to the bedding. Their appearance as well as the abundance of slivers and other carbonized

¹⁴⁸ E. W. Hilgard, "Report on Geology and Agriculture of the State of Mississippi," Jackson, 1860, pp. 152, 153, 155.

¹⁴⁹ G. H. Eldridge, "Reconnaissance in the Sushitna Basin, Alaska," Twentieth Ann. Rep. U. S. Geol. Surv., 1900, Pt. VII., pp. 21-23.

material suggests that these coal beds originated in a mass of decayed swamp vegetation. Locally, portions of the mass have lost the woody structure and resemble the higher grades of lignite, shading into bituminous coal. But, as a whole, this coal is in its youth and Eldridge thinks it doubtful if a younger example of coal can be found—peat excepted.

Darwin¹⁸⁰ saw in Chili a petrified forest in Tertiary rocks. Eleven trunks were silicified and 30 to 40 were converted into coarsely crystallized white calcareous spar. They had been broken off abruptly, the vertical stumps projecting a few feet above the ground. They were from 3 to 5 feet in circumference. "The volcanic sandstone, in which the trees were embedded and from the lower part of which they must have sprung, had accumulated in thick layers around their trunks; and the stone yet retained the impression of their bark."

The Miocene brown coal deposit at Gr. Raschen near Senftenberg has been referred to on a previous page: Potonié's¹⁸¹ description is that of a buried forest closely resembling those of New Jersey. It is very similar to the buried cypress swamps and forests of the southern United States, for *Taxodium distichum* is the dominant tree. As in the white cedar and cypress swamps, one finds in this brown coal deposit, 10 meters thick, successive generations of trees. The fuel is mined in open quarry and Potonié's plate shows the erect stumps distributed on the surfaces of several benches as they stood in the old forest, while the walls of the benches exhibit prostrate trunks in the intervening spaces, precisely as one sees them now on the surfaces of the forested swamps in America. These stumps, one third of a meter to nearly 4 meters in diameter, are, like those described by Cook and others, rooted in the peat, now converted into brown coal of excellent quality, as good as that which will come from the Dennisville peat in New Jersey.

There are few recorded observations of buried forests in the Mesozoic rocks; in very great part, those rocks were marine: The

¹⁸⁰ C. Darwin, "Journal of Researches," New York, 1846, Vol. II., pp. 85.

¹⁸¹ H. Potonié, "Ueber Autochthonie von Carbonkohlen-Flotzen und des Senftenberger Braunkohlen-Flotzen," *Jahrb. k. preuss. geolog. Landesanstalt.*, 1895, Separate, pp. 19-24.

latest Cretaceous in the United States is mostly of freshwater origin and it contains many coal beds; but there is no positive evidence that buried forests exist. Long ago, the writer saw, in New Mexico, great numbers of stumps and trunks in a sandstone, apparently of this age, and the same deposit has been mentioned by others; but there is no evidence on record to show that the stumps are *in situ*. Lyell was convinced that he saw vertical stems of *Equisetites* in place at a locality in the Triassic field near Richmond, in Virginia, but his observations are not sufficiently in detail to justify one in accepting them as evidence. It has been suggested that slender stems such as those of *Equisetum* or *Calamites* could not stand, while a sandstone accumulated around them; but the suggestion is without basis. The writer has seen slender canes on the Gulf shore of the Mississippi delta, which had been killed many years before by an invasion of salt water; but they were still erect, though sediment had accumulated around them to the thickness of several feet.

The "dirt bed" of the isle of Portland, belonging to the Upper Jurassic, was described long ago by Mantell.¹⁸² The uppermost Oolite stratum is a layer, one foot thick, of very dark friable loam, which seems to have been a bed of vegetable mould. It contains a large proportion of earthy lignite and also, like the modern soil of the island, waterworn pebbles and stones. This is the "dirt bed" of the quarrymen and upon it are branches and stems of conifers and plants allied to *Cycas* and *Zamia*. Many of the trees and plants stand erect as if petrified while growing undisturbed in their native forests. Their roots extend into the "dirt bed" and their trunks into the superincumbent limestone. At the time of Mantell's visit, a large area had been exposed by stripping:

"Some of the trunks were surrounded by a conical mound of calcareous earth, which had evidently, when in the state of mud, accumulated around the stems and roots. The upright trunks were in general a few feet apart and but 3 or 4 feet high; they were broken or splintered at the top, as if the trees had been snapped or wrenched off at a short distance from the ground. Some were 2 feet in diameter, and the united fragments of the prostrate trunks indicated a total length of between 30 and 40 feet. In many examples, portions of branches remained attached to the stems."

¹⁸² G. A. Mantell, "Geological Excursions Around the Isle of Wight," 3d Ed., London, 1854, pp. 287, 288.

Green,¹⁵⁸ visiting the locality some years afterward, remarked that the conditions recall those in interglacial buried forests of Great Britain; for the "brashy" soil, containing the stools of large trees, with here and there prostrate trunks, underlies a limestone carrying estuarine fossils. Other "dirt beds" appear occasionally, showing that the condition was repeated at some localities.

Passing to the Palæozoic, one finds many references to forests and trees buried in place, for excavations and explorations are extensive and the localities, unlike most of those in the Mesozoic, are in regions where scientific observers abound.

Al. Brongniart¹⁵⁴ saw at the mine du Treuil, near Saint-Etienne, a sandy bed, 10 to 13 feet thick, containing "a true fossil forest of monocotyledonous vegetables, resembling bamboo, or a huge *Equisetum*, as it were, petrified in place." These are erect. There were two types of stems; one cylindrical, jointed, striated parallel to their edges and the cavity filled with rock like that which surrounds them. The rarer forms are hollow cylindrical stems, diverging at the lower end "after the manner of a root but without presenting any ramification." Gruner¹⁵⁵ notes the existence of another forest at the same mine, but much lower in the section. The trees are *Syringodendron* and the roots rest on the coal. Brongniart refers to other localities, where vertical stems had been seen, and he cites Charpentier, who explained one rather notable case as due to landslides. Support for this conception was found in the débâcle of Lake Bagne, during which great trees were carried down with the mass and deposited in the original vertical condition position on the plain of Martigny. But Brongniart maintained that such occurrences must be rare, whereas vertical stems are found at many localities. At Treuil, as well as near Saarbruck, one finds not merely a single large trunk but many—a forest of slender stems, which have preserved parallelism among themselves. It is perhaps more difficult to conceive that sandy rock could envelop them after removal without destroying

¹⁵⁸ A. H. Green, "Geology," Part I., London, 1882, pp. 252, 253.

¹⁵⁴ Alex. Brongniart, "On Fossil Vegetables Traversing the Beds of the Coal Measures," *Ann. des Mines*, 1821. Trans. by H. de la Beche in "A Collection of Geological Memoirs," 1836, pp. 210, 216.

¹⁵⁵ L. Gruner, "Bassin houiller de la Loire," 1882, p. 226.

them, than to conceive that the deposit was made between them where they grew and were firmly rooted.

The discovery, near Manchester, England, of erect stumps, led several members of the London Geological Society to visit the locality. Hawkshaw¹⁵⁶ in 1839 and 1840 described five erect stumps and he was firmly convinced that they were in the place of growth. Bowman¹⁵⁷ in discussing the same occurrence, asserted that the loss of roots in the Manchester specimens was due to a process of fermentation. He combatted the notion that floated trees would remain erect, maintaining that, when they ceased to float, they would turn over. Several years afterward, Beckett and Sparrow¹⁵⁸ discovered some erect stumps near Wolverhampton, England. Beckett removed the coal attached to one of the trees. The stump was perfectly "bitumenized" but broken off at about 2 inches above the top of the coal, the inner portion being hollowed out to about the level of the coal. The stem was not flattened; it was approximately 4 feet in circumference and the roots spread out in a broad mass. The trunk and roots were covered with one half inch of bark, converted into brighter, more compact coal than that of the interior which was a mixture of coal and shale. The coal bed is about 5 inches thick. A few years later, Jukes¹⁵⁹ visited this locality with Beckett and, in writing about the stumps, he conceded that "they certainly looked as if they had grown there, and perhaps they may have done so, but even so, it by no means settles the question" [of origin of coal beds].

Beckett expressed no opinion respecting the original relations of the forest, but his paper is followed directly by Ick's¹⁶⁰ description, which is more in detail. The surface of the coal had been exposed by stripping in a rudely triangular space of about 2,700 square yards. Upward of 70 stumps were seen on this terrace, some of them more

¹⁵⁶ J. Hawkshaw, *Proc. London Geol. Soc.*, Vol. III., pp. 140, 269.

¹⁵⁷ J. E. Bowman, *Ibid.*, pp. 270, 271, 274.

¹⁵⁸ H. Beckett, *Quart. Journ. Geol. Soc.*, Vol. I., 1845, pp. 41, 42.

¹⁵⁹ J. B. Jukes, "The South Staffordshire Coal-field," 2d Ed., 1859, p. 201, footnote.

¹⁶⁰ W. Ick, "A Description of Numerous Fossil Dicotyledonous Trees at Parkfield Colliery near Bilston," *Ibid.*, pp. 43-45.

than 8 feet in circumference, all broken off close to the coal, while the prostrate trunks lie across each other in every direction. These trunks, 15 to 30 feet long, are invariably flattened to the thickness of one or two inches, but the bark is distinct on both sides. The bark is well preserved on the stumps, converted into bright coal, while the interior or woody part is dead looking, with dull luster like cannel. The stumps seldom rise above the surface. In some cases the diverging roots can be followed for nearly a yard, but they cannot be traced into the underlying shale. In some cases, *Calamites* are crowded between the trunks; *Lepidodendron* and *Lepidostrobus* are abundant on the surface, while among them one finds occasional remains of fishes. A noteworthy feature is that there are three coal beds within a vertical space of 12 feet, each of which shows on its surface the remains of an ancient forest—and the same beds are exposed a mile away. Beckett says that the coal, when "broken with the grain," shows faint impressions of *Calamites* and reed-like plants. Ick recognizes that "the position of the trees in each bed of coal seems almost to preclude all doubt of their having grown and perished on the spot where their remains are now found, and the roots are apparently fixed in the coal and shale, which was the original humus in which they grew."

Binney¹⁶¹ described the great *Sigillaria* stump, discovered at 7 miles east from Manchester and now in the museum of Owens college. The stump is filled with dark-colored fireclay but the roots with a different material. The dark fireclay floor was penetrated to about 3 feet by the stem and roots, the latter being, in part, directed upward.

De la Beche¹⁶² remarks that actual observations of rooted stems are comparatively few because exposures are few. He and W. E. Logan saw many vertical stems in a sandstone at a Welsh colliery. The directly underlying shale contained ferns and leaves of other plants distributed "around in the same manner as leaves and other parts of plants may be dispersed around stems of trees in muddy

¹⁶¹ E. W. Binney, "Description of the Dirkenfield *Sigillaria*," *Quart. Journ. Geol. Soc.*, Vol. II., 1846, p. 390.

¹⁶² H. T. de la Beche, "The Geological Observer," Philadelphia, 1851, pp. 482-485, 497.

places at the present day." The sandstone laminæ, by their arrangement, suggest the washing up of sand around stems in shallow water with small waves. This is shown more clearly at a locality in the Newcastle district, where one can determine the direction whence the current came by position of laminæ marking eddies behind the stems. Prostrate stems, often of same species with the vertical stumps, recall the prostrate trees among stumps in "submarine or sunken forests."

Dawson¹⁶⁸ first visited the South Joggins region in 1852, accompanied by Lyell. Somewhat later, he studied the section in great detail and gave his results in a series of memoirs published by the London Geological Society; but the final discussion appeared in the second edition of his *Acadian Geology*. Seventy coal horizons, some of them merely "fossil dirt beds," were seen in a vertical section of 4,700 feet and besides these there are many horizons at which rooted stumps were seen. Drifted trunks were observed in the sandstones, but those are neglected here, reference being made only to such remains as were associated with Stigmarian underclays.

Erect stumps were seen in the thin shale roof of Coal 13. In the interval of 38 feet between Coals 16 and 17 are several Stigmarian clays, one of which supports large stumps of *Sigillaria* with plant remains about their foot; the red shale roof of Coal 19 shows an erect *Sigillaria*, while erect *Calamites* stems are present over Coal 21 and a Stigmarian soil at some distance below Coal 22 bears a number of erect *Sigillaria* stumps. Division IV. shows erect stems of *Sigillaria*, *Lepidodendron* and *Calamites* at 44 horizons in a vertical section of 2,539 feet; several of the underclays, bearing erect stumps, underlie thin coal beds and, in at least one case, Coal 15, the erect stumps are associated with rain marks and footprints, clear evidence of sub-aerial position. At one horizon, the stumps yielded three species of batrachians with land shells and insects; those stumps are rooted in coaly shale forming the roof of a coal bed. "A coaly stump and an irregular layer of mineral charcoal, arising apparently from the decay of similar stumps" were seen in Coal 33a, while above that bed in a reddish shale is "a patch of gray sand-

¹⁶⁸ J. W. Dawson, "Acadian Geology," 2d Ed., London, 1868, pp. 150-179.

stone, interlaced with *Stigmaria* roots, as if the sand had been prevented from drifting away by a tree or stump." The Millstone Grit, in three divisions and somewhat less than 6,000 feet thick, shows erect *Sigillaria* in the lower portion, but most of the stems occurring in the sandstones are clearly driftwood.

One must keep in remembrance that Dawson's observations were made on the outcropping face of the beds along the coast; one may only conjecture what might be seen if some of the old soils were stripped as was the coal at Parkfield colliery.

Robb¹⁸⁴ described the rooted stump of *Sigillaria*, seen by him in the roof of a coal mine. The roots cross the slope, which is 11 feet wide; the conditions are shown well in the plate accompanying his report. He observed many *Sigillaria* stumps with their attached roots reaching into the coal seams. He notes one case, where a coal parting contains the roots of an erect tree, "which had apparently forced the layers asunder, 6 or 8 inches, for several feet from the extremities of the roots, beyond which the layers of coal unite again." In another, "where a large upright stem appears rooted in a coal seam, the latter seems to have been actually bent down by the superincumbent weight and, at a little distance, to have resumed its normal attitude."

Gosselet studied¹⁸⁵ the occurrence of erect stems at various levels in a vertical section and discussed their bearing upon the formation of coal beds. At Lens, there are three coal horizons within a vertical distance of 42 meters—Alfred, Leonard and Louise, with thickness respectively of 1.4, 1.6 and 0.6 meter. In the one meter thick shale under the Alfred, overlying an irregular *passée*, he saw two trunks, one resting on the *passée*, with the underlying coal slightly depressed, while, above, it terminates abruptly in a faux-mur, 5 centimeters thick, in direct contact with the coal. No roots could be traced. Five trunks were seen in the Leonard; one evidently had been floated in and a second was too indefinite for determina-

¹⁸⁴ C. Robb, Geol. Surv. Canada, Rep. Progress, 1874-5, pp. 196, 203, 204, 235, 237.

¹⁸⁵ J. Gosselet, "Note sur les troncs d'arbres verticaux dans le terrain houiller de Lens," *Ann. Soc. Geol. du Nord.*, Vol. XXIII., 1895, pp. 174, 175, 177-179, 181.

tion. Of the other three, two were implanted in a thin mur-like deposit covering the coal; the roots of one, a *Sigillaria*, spread out in the clay, but the roots of the other could not be traced. The roots of the third, in the coal, could not be recognized as *Stigmaria*, but they extended horizontally as clay masses covered with coal. The roots had been filled with sediment. Eight stems were seen in the Louise. Three rose directly from the underlying shale and crossed the mur, which is 60 centimeters thick; one was cut off abruptly at the coal and the others were broken off just before reaching it. The remaining five are in the roof. One is indefinite, but the others expand at the base and their rootlets are put forth into the shale. These erect trees, throughout, were *in situ*; all were vertical to the bedding. If they had been transported, they would have been inclined in direction of the current. Transported trunks were seen at various horizons but, in the cases described, the trunks were fixed in place by their roots, wherever the roots were seen. This Lens locality is in the great Westphalia-France-Belgium field, a paralic area.

Gosselet refers to conditions in the Banc des Roseaux at Commentry, where trunks are seen arranged in all directions, vertical, inclined, prostrate, and he compares them with those resulting from ravages of a hurricane in the forest of Mormal. There, many of the trees were prostrated; some, held by their roots, were inclined; while a small number remained erect—the conditions bearing remarkable resemblance to those observed at Commentry. His conclusion is that, where one sees the mur rich in rootlets of *Stigmaria*, he may regard it as a soil in which trees spread their roots. If the tree does not rise above the mur, it is because it has been destroyed by carbonization to furnish its elements, in part at least, to the coal bed. When the trunk is cut off sharply at coal or mur, it may be that the deposits were made so slowly that the trunk rotted off at the water-surface. He quotes Fayol as showing that at times one may prove the presence of erect trunks in the coal itself, but usually they are fused with the mass.

In this connection, it is well to recall the fact that Potonié¹⁰⁰

¹⁰⁰ H. Potonié, "Die Entstehung der Steinkohle," etc., 1910, pp. 134-136.

found frequent occurrence of *Stigmaria in situ* at Commentry. One notable discovery was that of a stump, whose roots spread out in an area of 6 meters diameter and retained their minute appendages. According to Renault, the branches extended farther but they could not be followed. Fig. 46, copied from Renault's description, justifies Potonié's remark that, if this be a transported tree, one must believe that it and the fine mud enclosing it had been transported together and deposited in the original position.

Schmitz¹⁸⁷ examined 33 erect stumps exposed in the roof of the Grande Veine of the Liège basin. The coaly crust, sometimes one centimeter thick, and the scars suggest that the plants are *Sigillaria*. The stumps are in a space of 2 by 95 meters, giving for each plant 5.6 square meters, a condition favorable to the belief that they are *in loco natali*. But he found that the trunks are all cut off at the coal bed; most of them show the enlargement belonging near the roots, so that one cannot suppose that the trees extended downward through the coal to the mur. On the other hand, the transition from coal to sterile rock above is barely one centimeter of coaly clay, so that they could not have been rooted in the toit. The laminae of this faux-toit contain many impressions of twigs of lycopods and *Equisetites*. Four of these pass under the bases of four erect trunks. This led Schmitz to think it impossible that the trunks were *in loco natali*; for if those four were not, there is no reason to suppose that the others were. To explain the condition, one must invoke transport. But, in a later paper to be considered in another connection, he gives the results of a more detailed study, which led him to recognize that the abrupt cutting off at the base was due to slips, which explained the presence of plant impressions under the ends of the free trunks.

Grand' Eury¹⁸⁸ summed up the results of his long study in a memoir presented at the Paris meeting of the Geological Congress,

¹⁸⁷ G. Schmitz, "Un banc à troncs-debout aux charbonnages du Grand-Bac," *Bull. Acad. Roy. de Belgique*, 3me Ser., Vol. XXXI., 1896, pp. 261-264.

¹⁸⁸ C. Grand' Eury, "Sur les tiges debout, les souches enracinées, des forêts et sous-sols des végétations fossiles et sur le mode et le mécanisme de formation de couches de houille du bassin de la Loire," *C. R. Cong. Geol. Intern.*, 1900, Vol. I., pp. 523-530.

drawing his illustrations mainly from conditions in the Loire basin. He exhibited twelve charts showing rooted trees and stumps discovered near Saint-Etienne during the preceding decade. Trees and stumps with roots attached were found belonging to *Stigmara*, *Syringodendron*, *Stigmariopsis*, *Sigillaria*, *Calamites*, *Calamodendron*, *Psaronius*, *Cordaite*s and other forms. In several cases, the leaves still remained attached. The arrangement of the roots depended somewhat on the soil in which they grew. Many times the more yielding soils permitted the roots to grow downward while in clays they tend to spread horizontally. Roots of *Stigmara*, usually, those of other plants, frequently, are interlaced in such manner as to leave no room for doubting that they are *in loco natali*. The soils of vegetation are distinct, for the roots are woody, herbaceous, or of several kinds, occurring in groups or singly, often interlaced, sometimes spaced but never scattered. They are therefore in place. Where there have been successive generations, the roots of the newer generations sometimes penetrate the stumps of their predecessors and in many cases pierce impressions of plants lying in the shale, through which they pass. The secondary roots of several types are thoroughly distinct at varying levels, while the creeping rhizomas at the base still remain attached to the stem; and one often finds buried at the foot of rooted trees the branches, leaves and fructifications which were detached during their growth.

Grand' Eury's conclusion is that Carboniferous plants were arborescent marsh forms, living as those in the Dismal Swamp, the foot and adventive roots in the water, with the stock and rhizomas creeping on the bottom. They could live either on the area of increasing deposit or in stagnant water. The fossil forests have no continuity; they disappear in all directions, often being reduced to mere groves.

It is unnecessary to give further illustration. One desiring to pursue the matter will find in Goeppert's "Prize Essay" a full statement of all information available at that time for eastern Germany, with full discussion. His studies, in some respects, are as interesting as those by Grand' Eury. Lyell, R. Owen, Lesquereux and Newberry have given examples for the United States.

The occurrence of drifted logs and clumps of vegetation is a phenomenon as familiar as that of buried forests; indeed, in the nature of the case, it is more familiar, as coarse rocks are more widely spread than are the coaly deposits. The battered snags of the Missouri-Mississippi and the logs scattered through the delta silts; the similar accumulations in tertiary deposits of the Missouri and Mackenzie; in the London Clay and on the New Siberia islands; the irregular pots of lignite in many places on the continent of Europe; the driftwood in our Newark formation; and the vast abundance of snags, logs and branches in sandstones of the Coal Measures in Europe and America; all bear witness, as do the buried forests, that conditions have undergone no material change since the closing epochs of the Palæozoic. These drifted materials are everywhere distinguishable from plants buried *in situ*, for they have been deprived of all tender parts; of the harder woods in Carboniferous times there are few traces except decorticated stems, casts of the interior, indeterminate forms grouped under *Knorria*, *Sternbergia* and some other names.

Conclusions.—It is strange that there should be such intense unwillingness to accept evidence in favor of the existence of ancient forests. Reasoning from existing conditions, one would have room for disappointment if such forests were not discovered in the older rocks; yet some authors seem to believe that one is chargeable with overcredulity if he regard buried stumps as rooted in place when they occur in the Coal Measures and his proof is demanded as emphatically as though he had asserted that man's normal position is with his head on the ground and his feet pointing skyward. The abrupt termination of stumps on the coal and the absence of roots are, for some, positive evidence that the trees are not *in loco natali*, though the condition is that which must come about in the cypress swamps of this day; the number of prostrate trunks predominates over that of erect stumps, and this is taken as evidence that all alike were transported; yet every great forested swamp shows that broken and overturned stems fall to be preserved in moist surrounding, while many stumps remain exposed to atmospheric action and, in large part, decay. The very presence of the stump itself is taken

to be evidence that it was transported, because one cannot believe that it would resist decay long enough to permit accumulation about it; yet the condition is familiar, for even the slender canes of the Mississippi delta, killed by salt water invasion, remain standing after they have been surrounded by several feet of silt. The filling of stumps by sand or clay is regarded as evidence that the change occurred after complete entombment in the mass of transported material; yet Potonié has shown that stumps on the shores have been found with the decayed interior replaced with sand even into the roots.

Some authors have laid no little emphasis on the Martigny débâcle as showing that landslides may explain those buried forests, whose *in situ* appearance cannot be denied. But aside from the fact that landslides are wholly exceptional and for the most part of limited extent, one may not utilize them as an explanation, unless it be supposed that, during the Carboniferous, landslides could occur amid conditions which would make them impossible now. According to some authors, the great coal areas were level regions; according to others, they were water basins, surrounded by a vast expanse of level area, forested or swampy. Under such circumstances a landslide like that of Martigny or even like that on the lower Adige could affect only the far away border area. But, in any event, the evidence of a landslide would be unmistakable; there would be no room for conjecture. The rock of the slide would be different from that at the same horizon a little distance away; and there would be ample evidence of disturbance in the underlying rocks, produced by downrush upon the water-soaked materials; certainly evidence of the débâcle would not be wanting. But no such evidence has been reported from any locality; on the contrary, where detailed descriptions have been given, one finds that the bedding is undisturbed and the conformability is complete. Equally, the buried trees are not relics of floating islands such as those of the Amazon and Congo, for they are not associated with filled valleys, but stand in and on rock of the type prevailing at the horizon for long distances.

THE FORMATION OF COAL BEDS.

III.¹

By JOHN J. STEVENSON.

(Read November 1, 1912.)

THE ROCKS OF THE COAL MEASURES.

Coal beds, Devonian, Carboniferous, Mesozoic and Tertiary, alike, are associated with shales, sandstones and, in many cases, with calcareous beds, the last often containing a marine or a fresh-water fauna. Interior or limnic basins frequently bear close resemblance to paralic or coastal basins, so that distinction between the types becomes arbitrary in some great areas. In the Indiana-Illinois field, wide invasions of the sea appeared again and again throughout practically the whole period of accumulation. On the other hand, the Appalachian basin, almost land-locked during most of its history, experienced few invasions and those, of comparatively small extent, were confined to the earlier periods; in the later stages, the whole region was practically limnic.

Study of reports by observers in the several countries makes certain that conditions needed for formation of coal beds were to

¹ Part I. appeared in these *Proceedings*, Vol. L., pp. 1-116; Part II. in same volume, pp. 519-643.

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all intents and purposes the same in all regions and in all periods, from the Devonian coals of Bear Island in the Arctic to the Tertiary coals of Wyoming or Trinidad; but the varying descriptions and explanations presented by students make equally certain that one cannot ascertain what the essential conditions are, if his investigation be confined to areas embracing a score or even several hundreds of square miles. The investigation must cover a great area, in which merely local features do not obscure those which are general and which actually bear upon the problem in hand. Such an area is the Appalachian Basin of the eastern United States, where one finds the Pennsylvanian or Coal Measures divided into

Dunkard	Greene
Wheeling	Washington
	Monongahela
Athens	Conemaugh
	Allegheny
Pottsville	Beaver
	New River
	Pocahontas

The order is descending.²

The Appalachian coal field, now embracing approximately 70,000 square miles of almost continuous deposits, occupies only a part of the original area. The deep synclinal basins of anthracite in eastern Pennsylvania are separated by 50 to 100 miles from the great bituminous region at the west, while southwardly one finds insignificant fragments along the eastern side until he comes to Georgia and Alabama. The greatest extent of the area of deposit was probably at the close of the Pottsville, when it reached from southern New York in west southwest direction to beyond central Alabama, more than 800 miles; at the north, it spread from the old Appalachian land, at the east, westward to beyond Newark in

²J. J. Stevenson, "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 18, 1907, p. 178. The Pottsville is subdivided in this paper into Beaver and Rockcastle. I. C. White, in West Virginia Geol. Survey, Vol. 1a, 1908, p. 13, has suggested that Rockcastle be replaced by New River and Pocahontas; this should be accepted, as Stevenson did not assign proper significance to Pocahontas, regarding it as merely a subordinate stage.

Ohio, while at the south it reached the western boundary of Alabama. The area of deposit at that time embraced not less than 200,000 square miles. The present outcrop approaches the western border at a few localities in Ohio and Kentucky as well as in Alabama, but for the most part it is two score or more miles east from the original limit. The eastern border is approached in the southern anthracite field of Pennsylvania and apparently it was not far eastward from the Pocahontas outcrop in Virginia; in Alabama, the eastern outcrop is not more than 25 miles from the original border on that side. But, in most of the space north from Alabama, the present continuous outcrop is from 30 to 100 miles west from that border as it probably existed at the close of the Pottsville. The Appalachian field included a small part of New York, more than two thirds of Pennsylvania, the western third of Maryland, nearly the whole of West Virginia, the eastern third of Ohio and Kentucky, with southwestern Virginia, eastern Tennessee, the northern half of Alabama as well as northwestern Georgia. Here then is an area of sufficient extent to provide ample illustration of purely local features and their relations to the effects of widely acting agents.

THE APPALACHIAN BASIN.

The Appalachian basin, from its origin to the close of the Palæozoic, was the scene of frequent changes in the relations of land and water. Schuchert and Ulrich^a have shown that such changes were merely commonplaces in the earlier periods. Those students are not in agreement respecting several matters, which have much interest from a philosophical standpoint, but they are in full agreement respecting all matters which concern the questions at issue here. As Schuchert has shown, the Appalachian basin originally was continuous with the broad Mississippi region and much of it was covered with sea. Toward the close of the Ordovician the Taconic revolution began, which, at the east, widened

^aC. Schuchert, "Palæogeography of North America," *Bull. Geol. Soc. Amer.*, Vol. 20, 1910, pp. 427-606; E. O. Ulrich, "Revision of the Palæozoic Systems," *ibid.*, Vol. 22, 1911, pp. 281-680.

Appalachia by additions along the western side from New England through Virginia, thus giving a great area on which erosion could work and did work, as evidenced by clastic sediments in the northern part of the basin. The Cincinnati uplift of authors, occurring at the same time, led to the elevation of Cincinnati (of Schuchert), the western boundary of the basin. Contemporaneously, as indicated by Schuchert, a less conspicuous land area, Alleghania, appeared within the basin, rudely parallel to Appalachia and extending southwardly across western Pennsylvania and eastern Ohio. It was separated from Cincinnati by the Ohio basin. During the Silurian, there was occasional communication across Cincinnati with the Mississippi region beyond and the faunas indicate that the basin opened northwardly to the Atlantic ocean. The same type of evidence shows that the basin was divided by a land area in southern Virginia, so that there was a northern sea extending into New York, as well as a southern sea in Tennessee and Alabama.

Studies by many geologists make clear that the southern portion of Appalachia was unstable. Southward from central Pennsylvania, the early Devonian rocks are wanting along the eastern side, while in southern Virginia and thence southward only the lower beds of the Middle Devonian are found. In Alabama the Devonian, more than 8,000 feet thick in central Pennsylvania, is represented by only dark shale rarely exceeding 100 feet and, near its southern limit, varying from 3 to 30 feet.

The area embraced in Schuchert's Alleghania was of decided instability. It received deposits during the Chemung, for that formation with its characteristic conglomerates crossed the area, though with reduced thickness; but all the principal elements of the section observed in central Pennsylvania are present. The intervals decrease toward this area and there is notable thinning above the upper conglomerate. The Catskill beds, following the Chemung, thin out against Alleghania, showing that once more it was above water. That formation, as defined by Vanuxem, the first to assign a definite meaning to the term, is 3,900 feet thick in Fulton county of Pennsylvania; 3,000, in the eastern portion of Bedford; 1,980 in western Bedford; it is concealed in Somerset,

except on the western edge, where it is brought up by a great anticline and is 10 to 15 feet thick, while, at 4 or 5 miles farther west in Fayette county, it has disappeared and the Upper Pocono beds of the Mississippian rest on the Chemung. The rate of decrease under Somerset is very nearly the same as that in Fulton and Bedford. This thinning is shown on the western side of the Catskill deposits from New York to New River in Virginia, beyond which southwardly Chemung and Catskill both disappear.⁴

The Carboniferous was opened by subsidence in the basin. The northern portion still received the greatest deposits along the eastern side in the old valley or "trough of sedimentation," but the area widened westwardly so that the later Pocono rocks of Pennsylvania overlap the Catskill of the Devonian and rest without apparent non-conformity on the Chemung rocks of Alleghania, as they do beyond in the Ohio basin. There was distinct widening eastwardly in Virginia and southward. Campbell⁵ showed that phenomena in Virginia, which had puzzled earlier observers, were due to overlap; that the coal-bearing Mississippian deposits rest there on Ordovician rocks, which in all probability had been upraised during the Taconian revolution. Still farther south, the oldest rocks of the Mississippian overlap the Catskill, the Chemung and, at length, even the thin Chattanooga shales, the last Devonian representative toward the south. But during succeeding stages of the Mississippian, there was distinct contraction of the area of deposit on the western side, for the Maxville lies within the Logan and the Shenango within the Maxville;⁶ at times, there may have been dry land in the Alleghania region. But at the south there was continued depression,

⁴J. J. Stevenson, "Bedford and Fulton Counties," Second Geol. Surv. of Penn., 1882, pp. 73-75, 81; "The Upper Devonian Rocks of Southwest Pennsylvania," *Amer. Jour. Sci.*, III., Vol. XV., 1878, pp. 423-430; "On the Use of the Name Catskill," *ibid.*, Vol. XLVI., 1893, pp. 330-337.

⁵M. R. Campbell, "Palæozoic Overlaps in Montgomery and Pulaski Counties, Virginia," *Bull. Geol. Soc. Amer.*, Vol. 5, 1894, p. 182.

⁶J. J. Stevenson, "Lower Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 14, 1903, p. 85. This paper, on pp. 89-96, contains a discussion of the varying geographical conditions during the Mississippian.

increasing southwardly, so that in that direction the thickness of the deposits increases until eastern Alabama is reached, where one finds progressive overlap and each deposit has its attenuated outcrop beyond that of its predecessor. Toward the close of the Mississippian, Alleghania was becoming better defined; all of the formations are present in most of it but they are very thin, nowhere more than 400 feet thick at the north, less than one fifth as much as in the anthracite region. Whether or not the Shenango shales of western Pennsylvania are synchronous with the upper red beds of the Mauch Chunk region cannot be determined, as a gap of 60 miles exists, from which the beds have been removed. Fossils are rare and insufficient for correlation; they make evident, however, that marine conditions prevailed in Alleghania, for the individuals obtained in southwestern Pennsylvania are large, well developed and thoroughly characteristic. The water was probably too shallow and too variable in distribution to permit abundant life; the sun cracks, ripple marks and other features indicate that these fine muds were spread out on mud flats, with constantly shifting areas of tidal waters. It is certain that withdrawal of the sea was continuous on the western side, so that before the close of Mississippian, the Ohio basin had become dry land and Alleghania had become once more a distinct ridge, dividing the basin longitudinally from New York to central Tennessee. But the withdrawal affected almost the whole of the Appalachian basin; and this withdrawal may have been caused by extensive deformation of the surface. While Alleghania was raised at the west, there was rejuvenation of Appalachia at the east. In the later Mississippian, the streams had reached base level along the borders, for only fine muds were carried into the basin; but the Pottsville opens with coarse deposits from Pennsylvania to Alabama.

The distribution and character of the Pottsville deposits¹ seem to place beyond doubt the assertion that at the beginning of the Pennsylvanian the whole basin, excepting at the southwest corner,

¹ D. White, "Deposition of the Appalachian Pottsville," *Bull. Geol. Soc. Amer.*, Vol. 15, 1905, pp. 267-282; J. J. Stevenson, "Carboniferous of the Appalachian Basin," *ibid.*, Vol. 18, 1907, pp. 142-150.

was a land area. Ancient Appalachia at the east towered above the old trough of sedimentation, now become a broad valley with irregular surface, while at the west rose the flat-topped Alleghania, hundreds of feet high at the north and separated from Cincinnati by the broad, shallow valley of the Ohio basin, which deepened southwardly. The eastern valley and the slope of Appalachia were drained by a river following the westerly side of the valley and finding its outlet at the south in Tennessee, where there still remained a considerable body of water. A gradually lengthening stream drained the western valley and found its outlet at the south in the body of water, which was continuous around the southern end of Alleghania.

The story of the Appalachian basin for the Silurian, Devonian and early Carboniferous is one of local deformations, of differential elevations and depressions, of alternating water and dry land areas, of sea invasions and expulsions or withdrawals. Similar conditions continued throughout the Pennsylvanian. The subsidence during the earlier stages was evidently differential, increasing toward the south. As one follows the New River formation along the face of the bituminous area, he finds not merely lower and lower beds but, in Alabama, also a vastly increased thickness in each member of the section, so that the mass, belonging apparently in greatest part to the New River, is greater than the whole column in the anthracite area, though that includes the Pottsville and at least two thirds of the Athens. The condition throughout the Pottsville was that of subsidence and the area of deposit constantly increased toward the west. Along the sides of Alleghania and in the Ohio basin, the New River overlaps the Pocahontas and the Beaver overlaps the New River. The character of deposits in the anthracite region and in Alabama affords ground for belief that, while subsidence prevailed within the basin to the end of the Pottsville, there was interrupted elevation in much of Appalachia, causing frequent rejuvenation of the streams and preventing eastward expansion of the area of deposition. During the Athens and later periods, that area seems to have been contracting steadily, first at the south and eventually on all sides until, at the close of the Dunkard, completion

of the Appalachian revolution brought deposition to an end in the comparatively small area which remained.

Before presenting in detail the evidence on which these statements are based, it is well to call attention to a matter respecting which some misapprehension seems to exist. Time breaks in deposition, due to existence of a land surface, do not leave in every case a record in the way of non-conformity, which can be recognized in even a considerable area. Schuchert^a has emphasized in this connection the conditions observed in the neighborhood of Louisville, Kentucky, where the limestone deposit is conformable throughout and appears to be continuous. The Devonian portion can be distinguished from the Silurian only by the fossils, although the portions are separated by a long land-interval. He offers many other instances to which the writer may add one, already referred to. In Westmoreland and Fayette counties of Pennsylvania, the Upper Pocono or Logan is shown resting conformably upon the Chemung, while at 60 miles east those formations are separated by not less than 4,000 feet of Catskill and Lower Pocono. Nor is it in any sense necessary that there be extensive erosion during a somewhat prolonged period of sub-aerial exposure, if the land be level or low-lying, even though the period be long enough to admit of the cutting of considerable valleys. Schuchert has shown that, though exposed during the whole period since the Taconian revolution, the Cincinnati region has lost certainly little more than 400 feet by erosion and that in all probability the greater part of this loss has occurred since the Pleistocene elevation. Ulrich^b says that a limestone in the St. Louis area, 5 feet thick, was exposed during the Silurian and the Devonian, yet it was not removed. Illustrations of the slowness of erosion, where land is level, are abundant in portions of Vermont, where one finds broad, terraced valleys in the Quaternary sands and gravels. The region has always been one with heavy rains, yet in some extended spaces the broad upper terrace is only slightly scarred, though, since it was aban-

^a C. Schuchert, "Palæogeography of North America," pp. 441, 442.

^b E. O. Ulrich, "Revision of the Palæozoic Systems," p. 306.

doned, the streams have cut their valleys, hundreds of feet deep, and have lined them with terraces.

The existence of a land area in Alleghania and the Ohio basin is made clear by the distribution of Pottsville deposits. The Pocahontas formation is present in the southern anthracite field and in the western part of the Western Middle, but it is wanting in the Eastern Middle and the Northern as well as in the bituminous region of Pennsylvania and Ohio. Along the eastern outcrop, it is present in the southern part of West Virginia and the adjacent part of Virginia, but it thins away quickly toward the west and north-west. It has not been recognized southwardly beyond Virginia. The New River is very thick in the southern and in the western part of the Western Middle, but is wanting in the northern anthracite field. It is very thick in eastern Alabama within the outlying areas, but it loses thickness quickly toward the west. This part of Alabama is a region of non-conformability throughout. Butts¹⁰ has shown that that unconformity is found at close of Cambrian, Ordovician, Silurian and Devonian. There is notable non-conformity of erosion between Mississippian and Pennsylvanian. The sandstone and shale mass, closing the former in eastern Alabama, was removed from a great space prior to deposit of the Pottsville. In the continuous bituminous region, one finds the upper beds of the New River at about 70 miles south from the Pennsylvania line; the lower beds appear in succession until in the southern part of the state one finds, in all probability, the whole formation. The formation is wholly wanting in the northern part of the state and in by far the greater part of Pennsylvania. Indeed, there seems to be good reason for doubting the accuracy of identifications along the eastern outcrop in the latter state. In southern West Virginia it is possible to trace the formation across the state by means of exposures and the many records of oil-borings preserved by I. C. White. The lower members disappear in succession westwardly against the face of Alleghania and only the uppermost members

¹⁰ C. Butts, "Iron Ores, Fuels, and Fluxes of the Birmingham District, Alabama," U. S. Geol. Surv. Bull., 400, 1910, pp. 14-16.

reach Kentucky. The formation can be followed easily along the eastern outcrop beyond central Tennessee, where the lower portion first crosses Alleghania, and becomes continuous with the deposit in the Ohio basin. There one finds the Bonair sandstone, midway in New River, passing across Alleghania, where it rests on Mississippian beds. On the western side in the Ohio basin, the higher New River beds disappear northwardly, each overlapped by its successor, so that beyond the Ohio River one finds only the top-most member occupying a long narrow space, extending almost to the present Lake Erie. At the close of the New River, most of the bituminous region within Pennsylvania and northern West Virginia was above the area of deposit. During the Beaver that area seems to have increased constantly so that, at the close of the Pottsville, Alleghania had disappeared and the Homewood sandstone or its equivalent covered the whole basin. The last portion of Alleghania to become buried was in Jefferson, Clearfield, Indiana, Westmoreland and Fayette counties of Pennsylvania. Differential subsidence continued throughout the Pottsville; even in the Beaver the condition is notable. That formation is 250 to 300 feet thick in western Pennsylvania, but on the Kanawha River in central West Virginia it is fully 1,000 feet, while in southwest Virginia the thickness seems to be even greater.

The Allegheny shows curious irregularities of thickness within the bituminous area, which are due clearly to local disturbances; but, leaving that feature out of view, one finds in a general way very little variation, except along the western border, where the section is shortened. The thickness may be taken as approximately 250 feet. In the anthracite area, the old trough of sedimentation continued and the great influx of materials from Appalachia gave a thickness several times as great. There, too, one finds anomalous deposition, with abrupt changes in structure of coal beds and remarkable variations in the intervals between them, evidence that there were many and serious local disturbances.

In the Conemaugh, there is less evidence of local disturbance. The variations are, as it were, regular. Measurements across the bituminous region show rapid thickening eastward to the Ohio

River but comparative uniformity thence to the eastern outcrop. In Muskingum and Guernsey counties of Ohio, the thickness increases from 315 to 340 feet but, 40 miles farther, at the Ohio it is 500 feet. In Pennsylvania and western Maryland the average is very nearly 600 feet. How thick the formation was in the northern anthracite field cannot be determined, as the top of the section has been removed, but the beds there are not less than 1,000 feet thick. The conditions were the same throughout the whole period of deposit, for variations in the upper half are similar to those in the lower half. Apparently there was slower subsidence along the western border than elsewhere, but no proof of overlapping or of regression can be found, as the outcrop is usually at a considerable distance from the border of deposit. There was a singular uniformity of conditions from north to south along the middle line of the bituminous area, a distance of more than 200 miles. At the most northerly outcrop in Pennsylvania, the thickness is approximately 600 feet and thence southward along the whole line it varies from 575 to 600 feet. Beyond Doddridge county of West Virginia, definite measurements cannot be made as coal beds and limestones alike have disappeared; but at Huntingdon, 100 miles beyond, and just west from the middle line the thickness is said to be 660 feet. At the extreme southeastern outcrop in West Virginia, the interval has been reported as 800 feet but some doubt remains as to the upper limit. Conditions during the Athens resembled those during the Pottsville, in that the trough of sedimentation with greater subsidence still existed at the east. But there was no longer differential subsidence toward the south and there is much reason for believing that there was notable contraction of the area of deposition in that direction, so that the Conemaugh may have extended, at most, only a short distance into Tennessee.¹¹

But when one reaches the Wheeling he finds a notable change. Going eastward from the western outcrop in Ohio, the thickness

¹¹ The measurements of the Conemaugh have been taken from J. J. Stevenson, *Ohio Geol. Survey*, Vol. III., 1879; *Second Geol. Serv. of Pennsylvania*, Reports K, 1876, KK, 1877, T2, 1882; I. C. White, *U. S. Survey*, Bull. 65, 1891; *West Virginia Geol. Surv.*, Vol. I., 1899.

of the Monongahela is 206, 250 and at the Ohio River 261 feet. Beyond that river, 275, 300, 340 and 380 in Pennsylvania to just beyond the Monogahela River; 316 at a few miles farther and 212 in the Frostburg basin of Maryland. Adding the coal beds and their partings one has 213 at the western outcrop, 270 at the Ohio River, 285 at western line of Pennsylvania, 400 near the Monongahela, 370 beyond the Monongahela and 252 in the Frostburg basin of Maryland.¹² It is evident that the topographical conditions have been changed and the area of deposit has become a trough with its deepest line midway in the bituminous region. The ancient trough of sedimentation at the east has disappeared. For in another direction the contrast with the Athens conditions is equally striking. No shortening of the section northward was observed in the Athens, but in the Monongahela, the shortening in that direction is distinct. Many measurements are available in southwest Pennsylvania and West Virginia.¹³ These show that the thickness increases from 156 feet at the most northerly exposure in Washington county of Pennsylvania to about 400 feet at the West Virginia line, the increase being gradual. The extreme thickness is maintained in West Virginia for more than 50 miles. Thence the section can be followed only with difficulty as all horizons become indefinite, but evidently it becomes shorter, for, where the horizons again become definite, along the southern border, the thickness is 250 to 281 feet. The conditions were similar during deposition of the Washington. Throughout the Wheeling, the area of deposition was basin shaped, with the rate of subsidence increasing toward central West Virginia. It was contracting on all sides and there is little or no reason to suppose that any important deposits were made in the anthracite region or south from West Virginia.

¹² Ohio Geol. Surv., Vol. III., p. 262; Second Geol. Surv. Penn., Report K, pp. 211, 216, 240, 340; "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 18, 1907, p. 47; G. P. Grimsley, "Ohio, Brooke and Hancock Counties," West Virginia Geol. Surv., 1907, p. 39.

¹³ J. J. Stevenson, Second Geol. Surv. Penn., Rep. KKK, 1878, p. 292; a considerable number of measurements cited here from Rep. K were made by I. C. White; I. C. White, U. S. Survey, Bull. 65, pp. 54, 55; Well records in W. Va., Vol. I.

The area of Dunkard deposits seems to have been much less than that of the Wheeling, but erosion has stripped the borders and one can make few positive statements respecting the conditions. The full section, as it now exists, is found only at rare places in the long narrow strip within western Pennsylvania and West Virginia. There appears to be the same tendency to northward shortening of the section; there is evidence in Pennsylvania that there were local foldings, that, as in the earlier periods, there were not merely general movements leading to decrease of the area of deposition but also others due to strains varying in direction at different times.

Evidence of elevation and subsidence is found in buried valleys, marking the courses of subaerial streams. These are so numerous that one need select only a few instances.

That Alleghania and the Ohio basin were dry land at the close of the Mississippian, is clear from the evidence of erosion as well as of corrosion. Hyde¹⁴ has summarized the observations of his predecessors and has added the results of his own studies. The base of the Coal Measures along the outcrop belt in southern Ohio rests directly on the Logan formations, which for the most part are Lower Mississippian. These were subjected to great erosion, which left a relief of 200 to 300 feet. Hyde followed this surface of unconformity across Ohio from the central line of the state southward to the Ohio River, finding frequent variations of 100 feet in the elevation. The Coal Measures sandstones are often let down into the Logan, but ordinarily the non-conformity is gentle. Here and there one sees old valleys which can be traced for considerable distances. The erosion was mostly post-Maxville.

Soon after the elevation of Alleghania and the Ohio basin, a stream began to cut for itself a valley, which, before the end of the New River stage, extended from the Canadian highlands southwardly across Ohio, Kentucky and Tennessee to an outlet at the

¹⁴ J. E. Hyde, "Notes on the Absence of a Soil Bed at the Base of the Pennsylvanian of Southern Ohio," *Amer. Journ. Sci.*, Vol. XXXI., 1911, pp. 557-560.

southwest. This stream must have been determined very quickly after the region became dry land, for, before the end of the New River, it had made a terraced valley, at least 30 miles wide in some parts of its course and showing irregularities of surface which indicate existence of many minor tributaries. The main stream had its source in the Canadian highlands; an important tributary drained part of the Mississippian ridge of Michigan and its course lay within the area of Lake Erie; a second important tributary came from the east, draining a part of southwestern New York and northern Pennsylvania. In Ohio, this valley area is for the most part west from the present outcrop of Pennsylvania beds; but its eastern side is traced readily from 10 miles south of Lake Erie to the southern border of Summit and Portage counties, about 80 miles, for it is filled with coarse sandstone and conglomerate, which thin out abruptly at the east, permitting the overlying beds to rest on Mississippian rocks. The western edge is approached in Wayne and Medina counties, where the coarse beds become very thin. Fragmentary exposures of the eastern side are found in counties farther south until, in Vinton, Jackson and Pike, the Pennsylvanian outcrop swings westward and the exposures extend to apparently midway in the valley. Thence into Kentucky the outcrop again trends southwardly and only the extreme eastern border is seen. In northern Kentucky, another valley, now filled with New River beds, begins in Carter county at 20 miles south from the Ohio River and deepened rapidly southward in Mississippian rocks. Its direction, west of south, is such that, within a few miles from the last recorded exposure, it should unite with the main valley. In southern Kentucky on the western side of the Main Valley area, M. R. Campbell discovered a valley in Mississippian rocks, deepening toward the east and now filled with New River beds. Farther south, in Tennessee, the relations soon become indefinite, but observations on the eastern side by Hayes make sufficiently clear that the valley was distinct at half way to the Alabama line until midway in the New River.

Some features of this valley should be emphasized. Its existence is distinct for not less than 400 miles and, beyond central Ohio,

it deepened rapidly toward the south. It was dug in soft rocks of the Mississippian, shale, limestone or comparatively fine grained sandstone; but it headed eventually in the Archæan rocks of Canada, while an important branch rose in the Mississippian area of Michigan, covered with a cherty limestone. A gradual though probably not continuous subsidence is shown by the distribution of New River beds, which terminate one after another in progressive overlap northward until beyond the Ohio River one finds only the newest members of the formation. In like manner, overlap is distinct on the eastern or Alleghania side of the valley; at the north, the Beaver rests on Mississippian beyond termination of the New River; Hayes and others saw that, in White, Bledsoe and Cumberland counties of Tennessee, the lower members of the New River thin away in succession on the west slope of Alleghania until at last the Bonair sandstone, midway in the formation, crosses the ridge where it rests on Mississippian. A similar condition exists on the eastern side of the ridge, facing the old trough of sedimentation.

The valley was filled eventually by New River deposits. In Ohio, only the latest members appear; coarse sandstone, of which the lower portion is dense, hard and white, containing quartz pebbles from the Canadian Archæan and pebbles of fossiliferous chert from Michigan. At many places in northern Ohio, this is a mass of pebbles with hardly enough sand to bind them, while mingled with them at times are irregular pieces of shale—the whole giving unmistakable proof of river action. The chert pebbles continue almost to the Ohio River at the south, more than 400 miles from the source, the measurement being made in direct line. The upper portion contains no chert but abundance of quartz pebbles, and in Jackson and Pike of Ohio, more than 300 miles from the only possible source, those pebbles, occurring throughout the deposit, are often as large as a hen's egg. In most of Kentucky, the equivalents of these later deposits are merely coarse sandstones with layers of small pebbles,—it must be remembered that there one sees only the border, not the deeper part of the valley. In the southern part of the state the beds consist largely of "hailstone grit," for there the exposures reach beyond those at the north. Soon after passing into Tennessee,

the rocks lose coarseness and within 40 miles, according to M. R. Campbell, are no longer hard enough to affect the topography; but in that interval a new sandstone, the Bonair, belonging lower in the column, is reached: fine-grained at first, it soon becomes coarse and within a few miles it is a pebbly rock, massive, 60 to 90 feet thick and containing very little clay. The rate of fall in the original stream cannot be determined as there was differential subsidence, but some conception may be gained from the thickness of deposits. The extreme along deepest part of the valley in northern Ohio is 175 feet; in southern Ohio, 310 feet remain and the original thickness was not far from 400 feet; in southern Kentucky, it was more than 1,000 and in central Tennessee not less than 1,500. The deposits are all of river origin; there is no trace of marine conditions, except at the extreme south, nor is there any evidence of shore action; the pebbles are round, not flat: proof of selective action by running water abounds along the whole course. One has here merely a subaerial valley, filled with river deposits. The main western drainage line followed the same course until late in the Athens.¹⁸

Roy¹⁹ has published some notes respecting the Sharon coal bed, the first member of the Beaver formation, which show that the closing deposits of the New River had become dry land, exposed to subaerial conditions. In the Mahoning valley that coal bed occupies serpentine, usually narrow troughs, which sometimes unite, but ordinarily are separated by long intervals of barren ground. The troughs were eroded in the old plain and the separating ridges are merely planed down knolls. In some cases, the troughs were eroded in Waverly rocks, which there are largely Devonian. The lowest coal bed in Jackson county, in the southern part of the state, is

¹⁸ This summary is based on observations by J. S. Newberry, M. C. Read, A. W. Wheat, E. B. Andrews, A. A. Wright for Ohio; A. R. Crandall, J. Lesley, G. M. Sullivan, W. M. Linney, M. R. Campbell for Kentucky; J. M. Safford, W. Hayes, M. R. Campbell for Tennessee. These are given in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 15, 1904, pp. 37-210.

¹⁹ A. Roy, "Third Annual Report of the State Mine Inspector," Columbus, 1876, pp. 129-131.

midway in the great sandstone mass filling the valley just described. It occupies a trough in that sandstone, showing that, during migrations of the stream in its valley, portions of the flood plain remained exposed long enough to permit accumulation of an important coal bed.

A valley of notable extent existed in western Pennsylvania during the early Allegheny. There is good reason for believing that it reached as far east as the border of Cambria county, but connected observations begin only in Jefferson county, somewhat more than 40 miles farther northwest; thence the course can be followed across southern Clarion, northern Armstrong, northern and western Butler into northern Beaver,—almost to the Ohio River, a distance of about 90 miles in direct line. The interval from the Vanport limestone down to the Homewood sandstone—the last member of the Beaver—is filled with coarse to pebbly sandstone in a strip, 8 to 10 miles wide, on each side of which the normal section is exposed. To trace this valley southward along the Ohio valley is not possible, as the horizon passes quickly under cover, but there are good reasons for supposing a southward extension. Borings at Wheeling, West Virginia, on the Ohio, report the interval filled with sandstone; at Moundsville, 10 miles south, a line of borings begins, which is continuous across Wetzel county of West Virginia into Greene county of Pennsylvania, in all of which sandstone fills the interval, thus indicating the existence of a long tributary from the east. It may be that the stream's course lay well west from the Ohio, nearer that of the pre-Beaver valley and that even the top member of the Beaver was invaded. Hodge reports that in Coshocton county of Ohio, a sandstone begins at 25 feet below the Vanport limestone and continues downward 280 feet to a thin coal bed resting on the New River conglomerate, thus passing through the whole of the Beaver.¹⁷

The portion of the column, beginning with the Vanport lime-

¹⁷ The observations by W. G. Platt, I. C. White, H. M. Chance, J. F. Carll and J. J. Stevenson, on which this summary is based, are recorded in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 17, 1906, pp. 65-228; J. T. Hodge, *Ohio Geol. Survey*, Vol. III., 1878, p. 572.

stone and extending upward for 75 feet or more, tells of stream erosions in a great area. That limestone is replaced with sandstone at many places in Pennsylvania is shown by I. C. White. Grimsley¹⁸ has described a "washout," which he observed at New Cumberland, on the Ohio River in West Virginia. It involves the Middle Kittanning coal bed and the associated rocks. The course of the "roll" is S. 30° E. The replacing sandstone is exposed along a stream near the town, where it is 1,200 feet wide. Approaching from the west, the coal is cut off, its thick underlying clay becomes sandy and the sandstone mass becomes continuous with that below the clay. This valley was filled during deposition of the sandstone which elsewhere forms the roof of the coal bed. Within the "roll," nodular and lenticular masses of coal occur along with numerous long strings, one and a half to 3 inches thick. This cut out was traced for about 2 miles.

The same horizon is marked by stream cutting in a considerable part of the Hocking Valley coal field of Ohio. The phenomena were described first by E. B. Andrews and at a later date by Orton.¹⁹ The latter is not inclined to believe that the work was done by streams, thinking rather that it was done by the ocean.

Illustrations of similar conditions are found abundantly in coal fields elsewhere. Ashley²⁰ has described the "Coxville Carboniferous river" in Parke county, Indiana, a Coal Measures valley filled with sandstone. It is 600 feet broad and the sandstone is exposed to a depth of 40 feet. On each side the sandstone spreads above the exposure and is seen resting on a coal bed. At another locality, the sandstone is 180 to 190 feet thick. At Silver Island in Fountain county and elsewhere the same features are shown at this horizon. It had been suggested that these, with some others, are parts of a drainage system, but Ashley hesitated to accept this, believing that if it were true there should be evidence of greater unconformity than has been observed. He remarks, however, that

¹⁸ G. P. Grimsley, "Clays, Limestones and Cements," West Virginia Geol. Survey, Vol. III., 1905, pp. 215, 216.

¹⁹ E. Orton, Ohio Geol. Survey, Vol. V., 1884, pp. 936, 937.

²⁰ G. H. Ashley, "The Coal Deposits of Indiana," Twenty-third Ann. Rep. Indiana Geol. Survey, 1899, pp. 272, 377, 385, 386, 552, 821, 956, 1261.

an extensive uplift in the northern part of the field would be sufficient. Channels are numerous at several horizons in Indiana and some of them seem to belong to a drainage system flowing south-west, as the smaller channels enter the larger in that direction and the larger ones increase in size. Non-conformity has been observed at many horizons in Indiana.

"Washouts" receive much attention in the British coal reports. Some are of slight extent vertically, of a type which will be considered in connection with the roof of coal beds; but there are others of serious importance, resembling those already described. Strahan²¹ states that in the Ebbw valley of South Wales, the Rock Yard and Three-Quarter veins have been washed out for 1,200 yards on one property, a vertical cut of not less than 110 yards. In another valley, the Rock has been removed for about a mile. Scott²² has described an old valley or estuary due to denudation and removal of Coal Measures beds. The earlier Coal Measures were removed and others deposited in their stead. Subsequently, some of the newer beds were removed and were replaced with others, also of Coal Measures age. Prestwich,²³ who long before Scott had discussed this "Symon Fault," recognized that it differs notably from the ordinary washouts of coal and that the Lower Coal Measures had been removed from an area of great length and breadth. The work, in his opinion, may have been done by subaerial denudation or by wasting currents. Fragments of coal and associated rocks are not uncommon in the newer deposits. Geikie²⁴ has given among others an illustration of contemporaneous erosion observed in the Coal Measures at Sanquhar, Scotland. Respecting all, he is compelled to the conclusion, "it is evident that the erosion took place, in a general sense, during the same period with the accumulation of the strata." De la Beche, in his "Geological

²¹ A. Strahan, "Geology of the South Wales Coal Field," Part II., 1900, pp. 65, 68.

²² M. W. T. Scott, "On the Symon Fault in the Colebrook Dale Coal-field," *Quart. Journ. Geol. Soc.*, Vol. XVII., 1861, pp. 457 et seq.

²³ J. Prestwich, "Geology of Colebrook Dale," *Trans. Geol. Soc.*, II., Vol. V., Part III.; "Geology," Vol. II., 1888, pp. 98, 99.

²⁴ A. Geikie, "Text Book of Geology," 3d ed., 1893, p. 506.

Observer," has discussed such occurrences in detail. Green²⁵ described several instances seen in the Yorkshire area. The Handsworth Rock, 40 feet of sandstone, disappearing towards north and south, fills a trough eroded in shale. The great deposit, known as the Rotherham and Harthill red rock, was deposited in a valley eroded in upturned Middle Coal Measures; and the deposition was earlier than the Permian, since the red rock underlies the magnesian limestone. The little coal basin of Commentry in France shows a striking example of contemporaneous erosion, which has been exposed in cross section by two of the great quarries. Toward the close of the period of deposit, a valley was eroded in the Coal Measures. Afterwards, this was filled by successive deposition with light-colored sands and gravels. At a somewhat later date, an eruption of igneous rock in the immediate vicinity pushed these horizontal beds into a compressed, somewhat complex synclinal and folded the older beds beyond into overturned folds, while faulting the Grande Couche, to whose roof the erosion had reached.²⁶ The same process of erosion was repeated in later times and a newer filled-valley has been exposed during deepening of the eastern tranchee.

Contemporaneous erosion provides evidence that the rocks underwent folding during deposition of the Coal Measures. A few notes from southwestern Pennsylvania will suffice for illustration and, no doubt, they will recall to the reader instances in other localities.²⁷ The Washington-Brady Bend anticline is crossed by the Monongahela River at Pittsburgh and the Claysville anticline is crossed by the Ohio River at a short distance farther west, near Woods run. These folds existed in the later part of the Cone-

²⁵ A. H. Green, "The Geology of the Yorkshire Coalfield," London, 1878, pp. 397, 456, 481-484.

²⁶ J. J. Stevenson, "The Coal Basin of Commentry in Central France," *Ann. N. Y. Acad. Sci.*, Vol. XIX., 1910, pp. 198, 199. H. Fayol has presented a very different explanation of the phenomena in "Reunion extraordinaire dans l'Allier," *Bull. Soc. Geol. France*, III., Vol. XVI., separate, pp. 35-37.

²⁷ Second Geol. Survey Pennsylvania, Rep. K, 1876, pp. 310, 311, 324-326; Rep. KK, 1877, p. 303.

maugh and had lifted much of the region above the area of deposition. On the latter fold, a deep railway cutting shows sandstone, 25 feet thick, resting on shales with limestone. At a few rods west, the sandstone suddenly becomes 75 feet thick, replacing the underlying beds; but, within two miles, the lower part of the sandstone disappears almost abruptly and the normal section reappears. The same sandstone was seen in another section farther north, but, in that direction, the horizon soon passes into the air while southwardly it passes almost at once under cover. The rocks on each side of this valley have a dip of 80 feet per mile, whereas that of the sandstone within is but 40 feet. The crest of the Washington axis is shown well in a railway cutting. There, the shales overlying the Ames limestone, midway in the Conemaugh, come down and replace that limestone and underlying beds to an unknown distance below the roadway; but at barely half a mile the normal section is reached. This is clearly on the crest of the fold, for the Ames limestone dips in opposite directions on the sides of the shale-filled space. On the west slope of the Salzburg anticline in Westmoreland county, near Penn station, one may see an illustration of alternating erosion and deposition, in type resembling the "Symon Fault." This is in the Monongahela formation, somewhat more than 100 feet from the bottom. At the entrance to a long railway cutting, a sandstone, 60 feet thick, rests on 6 feet of irregular sandstone, containing streaks of coal. Within a few yards, 8 feet of limestone is shown under the upper sandstone but it continues for less than 20 yards and is cut off abruptly by the sandstone. In a branch cutting, the sandstone is well exposed for a short distance but is soon replaced with yellow shale, which is very local.

Aside from the continued contraction of the area of deposition, there is little evidence of great movements within the Appalachian basin. For considerable periods of time, areas of many hundreds of square miles received no deposits; the anticlines evidently were developed slowly. The Appalachian revolution apparently spent its force during Coal Measures time mostly at the east. But in Europe the Upper Carboniferous disturbances have left more note-

worthy records. Barrois,²⁸ long ago, showed that the great movement in the Cantabrian area occurred between the Middle and the Upper Coal Measures. Douville had found evidence of similar conditions in the Rhine country and had concluded that the movement was general between Saxony and the Vosges. Barrois recognized the time as one of great denudation and reworking of materials, for the conglomerate of Tineo came partly from Carboniferous rocks. More recently, he has shown by stratigraphical and palæontological evidence that in the Nord basin there exist two anticlinals within rocks of the lower coal terrain.

Angular and rounded fragments of coal have been found in sandstone, shale, limestone and even in the coal itself; that such occurrences have an important bearing on hypotheses respecting the formation of coal beds has been patent to students everywhere but no systematic studies have been made by any except within very recent years. The conditions deserve careful consideration.

The earliest recorded observation, found by the writer, is that by Logan,²⁹ who referred to pebbles of coal and coal shale in the Pennant as though they were familiar objects. De la Beche speaks of them in the same way in his "Geological Observer." Some of the pebbles are 2 to 3 inches in diameter and exhibit the definite cleavage. Rounded pebbles of coal belonging to the lower series have been found in the upper—and it is certain that the coal, in some cases, was hard when removed, for at quarries in Swansea, *Sigillaria* stems show impressions of the pebbles. Jukes,³⁰ in discussing the evidence of unconformity between the Carboniferous and the Permian of South Staffordshire, finds additional proof in the pres-

²⁸ C. Barrois, "Recherches sur les terrains anciens des Asturies et de la Galice," *Mem. Soc. Geol. du Nord.*, Vol. 2, No. 1, pp. 599, 600; "Exposé de l'état des connaissances sur la structure géologique du bassin houiller dans le Département du Nord," Lille, 1909, p. 20.

²⁹ W. E. Logan, "On the Character of the Beds of Clay lying immediately below Coal Seams of South Wales," *Proc. Geol. Soc.*, Vol. III., 1840, p. 276.

³⁰ J. B. Jukes, "The South Staffordshire Coal-Field," 2d ed., 1859, p. 136.

ence of angular and rounded fragments of Coal Measures rocks with pebbles of coal in the lower part of the Permian.

Andrews³¹ found in the lower part of a sandstone overlying the Nelsonville coal bed a rounded fragment of coal, measuring 4 by 2 inches. It bears so close resemblance to coal from Straitsville, only a few miles away, that he believed it derived from that place—the coal bed being the same at both localities. This great coal deposit is only 200 feet above the bottom of the Ohio Coal Measures. Andrews is convinced that the coal had been completely formed by the time that 12 feet of shale and one foot of sandstone had accumulated at Straitsville. He observed irregular fragments of coal, some angular, others rounded, in a sandstone within Wayne county of West Virginia.

Jordan³² states that the Welsh Coal Measures are divisible into the Pennant Grit above, with few coal seams, and a lower division, mostly shale, with numerous coal seams. He found no coal pebbles in the lower division, but in the lower part of the Pennant they are present, associated with pebbles of granite. Logan's pebble of cannel was found in slate overlying a bed of ordinary coal and was supposed by him to have been derived from a bed, 2,000 feet lower in the series. Jordan objects that there is no evidence that the lower beds were upraised and denuded before deposition of the upper beds. He thinks that the pebbles were derived "either from the seam of coal above which they are found or from the destruction by erosion of a seam of coal, which once existed approximately in the position in which they are found, the erosion in either case being effected by the strong water courses which distributed the grains of sand and other material upon the coal seam." He refers to the "Rock Fawr" seam near Bridgend, where the sandstone roof contains a notable quantity of slightly rounded pebbles of coal, similar to those of the underlying seam. Logan's pebble, he thinks, came from a superficial layer of cannel in the Penslawdd seam. The

³¹ E. B. Andrews, Ohio Geological Survey, Vol. I., Part I., 1873, pp. 355-357.

³² H. K. Jordan, "On Coal Pebbles and their Derivation," *Quart. Journ. Geol. Soc.*, Vol. XXXIII., 1877, pp. 932, 933.

effects of a water current are seen in the Forest of Dean, where a coal seam, 5 to 6 feet thick, was washed out in one portion of the colliery and redeposited in another, where it is 8 to 12 feet thick. The character of the pebbles led him to the conclusion that the coal, prior to deposition of roof materials, "was to great extent consolidated though perhaps only partially indurated."

In discussing this paper, Moggridge stated his belief that the pebbles were derived from broken up coal beds, the debris being distributed in the newer deposits. There is a bed of good cannel only 4 miles from Penslawdd, so that one need not look far for the source, the more so since the cannel is at greater altitude. Morris thought the pebbles derived from one of three sources; they might be fragments of floating wood encased in sandstone and carbonized, they might come from the breaking up of submerged forests, whose fragments became embedded in sands and clays, or from the breaking up of coal beds. Jordan could not accept Moggridge's suggestion, because the present greater altitude of the cannel bed is due to late movements, or those of Morris because the pebbles are confined to sandstone roofs and are not distributed throughout the series.

It is well to introduce here, in advance, notes having some bearing on the matter in hand, though more upon another, which will be considered in connection with coal beds themselves. Stevenson²³ found coal fragments in a sandstone overlying the Pittsburgh coal bed. At one locality, the lower layers "contain lumps of coal, coarse pebbles and fragments of vegetable stems, the whole looking as though its deposition was accompanied by enough disturbance to tear off part of the old swamp. It is clear, however, that not all of the fragments found in the stratum belong to the same bed. Some of them are crushed and fractured in such manner as to show that they were consolidated before removal, while others are saucer-shaped." He thinks that the latter came from the Pittsburgh coal bed and that the others were derived from an older bed, outcropping at some distance eastward. At another locality, the derivation is

²³ Sec. Geol. Surv. Penn., Report K, 1876, pp. 90, 137, 285; Report KKK, 1878, pp. 79, 81, 87, 118.

local, for the upper division of the Pittsburgh has been removed and its fragments distributed in the overlying sandstone. The condition is in no wise unusual. In a later report, he says that the Homewood sandstone, the closing deposit of the Beaver, contains in its lower portion disks and pots of coal of shape such as one might expect where a soft mass has been entangled in sandstone and subjected to heavy pressure. At another locality, the sandstone contains coal fragments, some quite large, which he thinks represent a coal bed removed from the area during deposition of the coarse more or less pebbly rock. As that rock in this locality fills an old valley, it is possible that the larger fragments represent boggy material accumulated on undermined banks. In some places mentioned by this observer, the fragment-bearing sandstone rests on the uneroded Pittsburgh coal. In all probability, a sand-laden stream, sweeping across the area, removed part of the unconsolidated coal and carried it away to be deposited on an overflow surface along with living plants, as well as with the sand and hardened coal brought from a distance. The same observer mentions a locality, where the coal had been cut out and replaced with a confused mass of coal, slate and sandstone. I. C. White²⁴ has recorded several instances similar to the last, in widely separated localities, where the coal has been replaced with a conglomerate of worn and rounded pieces of limestone, coal, slate, and sandstone.

"Washouts" similarly filled have been reported by other observers in Pennsylvania and elsewhere. The conditions are precisely such as one can see in the streams now flowing across the bituminous field and the conclusion is the same in both cases—that the stream flows across the outcrops of rocks whose fragments are in its bed or in the "bottom" deposit of its banks. The Banc des Chavais in the Grande Couche of Commentry belongs to this type.

Renault²⁵ studied very carefully the coal pebbles found in the sandstones of the Commentry coal basin. Some resemble freshly

²⁴ I. C. White, Second Geol. Surv. Penn., Report Q, 1878, pp. 114, 268; Report Q2, 1879, pp. 270, 274-276; Report Q3, 1880, p. 176.

²⁵ B. Renault, "Quatrième note pour servir à l'histoire de la formation de la houille," *Comptes Rendus*, Vol. 99, 1884, p. 201.

broken coal, but others are pebbles with the angles rounded. Their coal differs from that of the beds in that it is less compact, absorbs water, has less brilliant fracture and can be cut more readily. It has the alternate bright and dull laminæ of ordinary coal. Apparently, the conversion was not complete when the fragments were torn away and the interrupted process was not renewed. He concludes that, during formation of the Commentry coal terrain, there were frequent erosions of the earlier beds of coal, clay and limestone; that those beds do not belong, as might be imagined, to a much older coal period; that the coal, found as pebbles, is, so to speak, less advanced, offering some properties differing from those of plant materials fully converted in place; that the time required for conversion of vegetable matter into coal, though very long, appears not to be excessive, since a coal basin of moderate size already possessed some coal, while the deposits were increasing. There can be no doubt respecting Renault's conclusion as to the source. No rocks older than Middle Coal Measures are known to exist in this basin of barely 12 square miles, which is divided by the broad dejection cone of Montassié, which contains no coal.

Fayol's²⁸ observations, recorded in his original work as well as in the résumé published in 1890, are of no slight importance in this connection. Pebbles of coal, angular or rounded, in all shapes and varying in size from mere grains to 4 decimeters, occur in all parts of the terrain within the Commentry basin. They are rare in the conglomerates but abound in the medium-grained sandstones of both les Pegauds and les Ferrieres, the coal-yielding divisions separated by the barren Montassié area. They are associated frequently with grains and pebbles of carbonaceous shale. The character of coal in the pebbles varies. Those in the older part of the formation are anthracite, like the adjacent coals; those in les Ferrieres are meager, as is the coal of that area; while those of les Pegauds are of flaming coal like that from the Grande Couche. So that the coals of the pebbles are like those of the immediate area. At the same time, it is all-important to note that, according to Fayol,

²⁸ H. Fayol, "Études sur le terrain houiller de Commentry," livre premier, *Bull. Soc. Ind. Min.*, 2me Ser., Vol. XV., 1887, pp. 140, 141.

pebbles of anthracite have been obtained near the Grande Couche and that in some pebbles the coal has the appearance as well as the composition of lignite. But these last are exceptional—they, evidently, are of the type studied by Renault. The distribution of the pebbles is absolute proof that, before the Gres Noirs coal bed was formed in its present area, not only the older rocks with anthracite, but also the Grande Couche itself and its associated beds were exposed to subaerial streams, by which the pebbles of coal and carbonaceous shale were rounded. The writer collected many of these pebbles from a sandstone at less than 60 feet above the Grande Couche.

Barrois³⁷ says that pebbles of coal are less numerous in the paralic basins of north France than in the limnic basins of the plateau, but he had opportunity to study some which had been discovered recently. Geologists, in the majority of cases, have believed that coal pebbles had travelled for only short distances and that they prove the process of conversion far advanced when the fragments were detached; but some, objecting to such rapidity of conversion, have preferred to believe that the fragments, when entombed, were merely rolled vegetable matter. He notes the statement respecting the Commentry pebbles, that some, at least, show contraction, evidence that the conversion was not complete. The marshes of the Pas-de-Calais, attacked by tides, give off blocks of peat, which become rounded and at length ellipsoidal. E. Geinitz has made a similar observation on the Baltic shore near Rostock. The Bruay pebbles occur in hard coarse sandstone, are from mere grains to 14 by 5 by 3 centimeters. They are chiefly cannel, at times have laminæ of brilliant coal and, under the microscope, they show vegetable structure—they recall the peat pebbles of the Pas-de-Calais. They have suffered contraction, for they are surrounded by a film of calcite which penetrates the pebbles in veinules.

As the result of his studies, Barrois has found that coal pebbles usually occur in coarse sandstones above coal beds; that they have

³⁷ C. Barrois, "Observations sur les galets de Cannel-coal du terrain houiller de Bruay," *Ann. Soc. Géol. du Nord.*, Vol. 37, 1908, pp. 3 et seq.

the coal of the area, not differing materially in volatile content; that they belong to some coal bed not far away, for one never finds *maigre* pebbles in a *gras* area, or the reverse; that pebbles of *cannel* occur more frequently than those of ordinary coal. These conditions hardly justify the supposition that the pebbles were brought by streams flowing over beds, which, already coal, alternated with shale and sandstone. The Bruay pebbles are all from one coal bed and that must have been near by. The presence of laminæ of brilliant coal in the sandstone, identical with the laminæ in the *cannel*, leads to the same conclusion, because in the Nord basin, as in South Wales, *cannel* is in the roof of the beds. When a coal bed is eroded, the *cannel* is the first portion to be removed, which explains the frequent occurrence of *cannel* pebbles in areas where that type of coal is rare. Barrois concludes that the Bruay pebbles came from one bed, in which the material was not wholly converted. The erosion occurred simultaneously over an extensive area and was due to changes in course of a stream, loaded with sediment, which inundated the bog abruptly. It must have come from a distance, for the deposit contains elements of crystalline rocks, larger and more abundant than in any other clastic deposit within the basin.

Petrascheck⁸⁸ investigated the mode of occurrence of coal pebbles in a sandstone within the Galician area. The deposit is thick, usually only moderately coarse, but in the portion carrying the pebbles it becomes irregular and conglomerate. Some fragments of coal are distinctly rolled, some have merely rounded angles, while others have the edges sharp. The minutely pitted surface of some fragments led him, at first, to imagine that they had been peat when entombed, the pitting being due to pressure by sand grains. But the conditions throughout compelled him to abandon this conception. The form and substance of the pebbles favored belief that at the time of burial the material was already hard. Glance coal breaks into angular pieces and can endure little chafing, while *cannel* and

⁸⁸ W. Petrascheck, "Das Vorkommen von Steinkohlengerollen in einem Karbonsandstein Galiziens," *Verhandl. k. k. Geol. Reichsanst.*, 1909, Wien, 1910, pp. 380 et seq.

carbonaceous shale are rounded easily. The contrasts are shown well by fragments in this sandstone, for the glance coal is angular and the cannel rounded. Fragments of slaty coal also are rounded, but the shale portion resisted better than the coal portion and the fragments are flatter than those of cannel. The bond between coal and shale must have been, at entombment, such as is seen in slaty coal now. It might be supposed that the pebbles are buried fragments of wood; but such complete penetration of wood by shale is inconceivable; there would be, moreover, so great change in volume that the fragments could not retain their form. He is convinced that the consistency of glance on the one hand and of cannel on the other is so different as to make certain that the materials had acquired their characteristics before burial. The source of the pebbles cannot be ascertained, but they do not appear to have come from any contiguous bed, and the only suggestion possible seems to be that they have been derived from much older deposits. The features of the rock carrying the coal pebbles, especially its coarseness, in which it differs from the sandstone on each side, seem to suggest that it may occupy a valley eroded in the sandstone.

Coal pebbles are not confined to the Coal Measures. Haast³⁹ found them in Cretaceous sandstone of northern New Zealand and Hutton found them abundant in a conglomerate of the same age in Otago, where the rock rests on the eroded surface of a coal bed. Fragments of coal have been reported by the writer from upper Cretaceous sandstones of New Mexico and a large block of oolite coal was obtained in the chalk of Kent, England. A more curious phenomenon is the existence of apparently rolled pebbles in the coal itself. Gothan⁴⁰ states that in the Lias area of Fünfkirchen, Hungary, there is, near Vasas, abundance of "Mugelkohlen," round to ellipsoidal fragments of pure coal, embedded in almost all of the coal beds. In size they vary from nut to two fifths of a meter;

³⁹ J. Haast, "Report on the Geology of the Malvern Hills, Canterbury," Geol. Surv. New Zealand, 1872, pp. 50, 52, F. Hutton, "Report on the Geology and Gold Fields of Otago," Dunedin, 1875, p. 106.

⁴⁰ W. Gothan, "Untersuchungen über die Entstehung der Lias-Steinkohlenflöze bei Fünfkirchen (Pecs, Ungarn)," *Sitzungsber. d. k. preus. Akad.*, Vol. VIII., 1910, pp. 136-143.

the surface is smooth, metallic and lustrous, often with a scale-like coating such as one sees on concretions. They are separated easily from the surrounding coal, to which they are not related, and they do not occur in the associated rocks. Gothan considers the various suggestions offered to explain the occurrence of these nodules, but finds them either insufficient or not in accord with the conditions. He seems to be convinced that they are pebbles, owing their rounded form to attrition. The Geological Survey collection at Berlin contains similar forms from a mine in the upper Silesian Carboniferous, where the pebbles of coal are associated with others of quartzite, granulite, etc. There and at other localities the association is evidence of transport, but, at Vasas, rock pebbles are unknown. Gothan sees no reason to suppose that they came from a distance. He conceives that they may have been formed even while the Jurassic Waldmoor existed and that wind-moved water may have detached pieces of the harder peat. The more resistant portions of those pieces would be rubbed against each other until rounded and eventually they would sink into the peaty mud. These "balls" occur elsewhere. Hughes found⁴¹ balls of very pure coal enclosed in coal beds in India and Stainier reports that at Turon in Asturia there is a bed formed wholly of rolled pebbles of coal; he mentions two localities in Australia, where coal pebbles are embedded in coal of notably different composition and states that such pebbles occur in the coal basins of Mons and Charleroi, Belgium.

These citations suffice to illustrate the varying conditions in which coal pebbles or fragments occur in clastic rocks or even in coal beds themselves. Gothan's explanation for existence of balls in coal may account for origin of the material. A broad stream meandering through a deep bog might easily tear off small fragments, as supposed by him, but even then the necessity for transport remains, since there could be no sufficient chafing in quiet or gently moving water. In all other cases, the transportation is clear.

⁴¹ T. Hughes, "The Jherria Coalfield," *Mem. Geol. Surv. India*, Vol. V., pp. 254-256; X. Stainier, "Des rapports entre la composition des charbons et leurs conditions de gisement," *Ann. des Mines de Belgique*, Vol. V., 1900, pp. 95-97.

In some instances, the distance was small or the detached pieces were enveloped in sands and swept along as part of the mass to the place of deposition. This was evidently the condition where one finds irregular chunks and petty lentils of coal as in the sandstones of western Pennsylvania and at many places in other coal fields. These masses, torn off by a sand-laden stream, were transported without material attrition and were deposited where the speed slackened on an overflow surface. It must be noted that one rarely finds such masses in localities where the underlying coal bed shows evidence of erosion; very often the sandstone with coal fragments rests on an uneroded coal bed; while in very many cases the sandstone resting on a bed with channeled top is wholly without noteworthy fragments. The channel was dug in the vegetable material and was filled with sand of later arrival. It is difficult to conceive how material torn from a bed could be deposited over or very near the place of origin, unless one imagine a whirlpool of modest area; but it is easy to understand how a sand-laden stream flowing irregularly across a plain, covered with a thin marsh, could remove the cover and deposit it elsewhere. That condition is approached in considerable areas by streams like those of the Paraguayan region, where the channels are aggraded quickly in flood time and the turbid waters are driven to seek new courses.

But if the coal fragments be rounded, they point to conditions wholly different from those just considered. In the summary of observations given above, there are references to the process of conversion and to the time required for its completion. Those topics lie, for the most part, outside of the question in hand and are related to it only incidentally; but the structure and composition of coal in the pebbles make certain that it was already well advanced in conversion when removed from the bed. The Commeny pebbles in some cases were already anthracite while others, those from the Grande Couche, were still flaming coal; for both types are found in the same sandstone—that above the Grande Couche—and, along with them, are thoroughly rounded pebbles of carbonaceous shale.

In not a few localities the pebbles are cannel and they have been

regarded as derived from the cannel bench of an underlying bed. That cannel pebbles should retain their shape and size better than those of glance coal is normal, because cannel is tough and glance is brittle; but there is no reason to suppose that sapropelic muds became hard and resistant with great speed while the underlying felted peaty materials became compacted slowly. It would seem more probable that cannel pebbles are more numerous because cannel survived the shocks of transport and the glance coal was reduced to minute grains. The evidence that the pebbles have undergone much change since entombment seems to be slight and of hardly material importance. The writer, during a second visit to Commentry in 1910, examined very closely more than 100 coal pebbles scattered through the sandstone up to 60 feet above the Grande Couche. In only two, possibly three, was there appearance of contraction. Almost without exception, the pebbles were coated by a thin film of clay, such as commonly covers, in whole or in part, coal fragments on beds of actual streams in the Appalachian basin. This mud-coat, by drying, might leave a space in which a film of calcite could be deposited; but, aided by strong pocket-glass, the writer could find no evidence of contraction in the pebbles. There had certainly been no change after the sandstone was compacted. Fracture planes are rarely seen but, in very many pebbles, the typical cleavage is distinct. The pebbles of shale are not clay balls; they are fragments of laminated shale. In any event, the form of the pebbles, shale and coal alike, is that due to stream transport. Some indeed are flattened like coast shingle, but that is due merely to the original form, a block with laminated structure. Every feature of these pebbles appears abundantly on the beds of streams flowing across the Pittsburgh coal area of southwestern Pennsylvania. They leave no possible room for doubt that the coal fragments, like those of sandstone and shale, were deposited by streams flowing over outcrops of coal, shale and sandstone.

In the larger areas, pebbles are not distributed indiscriminately throughout the mass of sandstone or shale; they are localized. Petrascheck's descriptions as well as those of the Silesian area by Gothan recall the conditions observed in western Pennsylvania but

they seem to be in channels within sandstone, whereas those of Pennsylvania are channels within coal beds. The coal pebbles in the latter localities could not have come from the enclosing coal; all of them, coal, sandstone, shale, limestone, are rounded as by stream transport and the rounding is such that they must have been brought from a considerable distance. Everything about these pebbles of coal indicates that, during much of Coal Measures time, a considerable part of the area of deposition was land, showing outcrops of the various types of Carboniferous deposits, whence flowing streams gathered their loads of detritus. With varying conditions, streams shifted their courses or washed down the materials accumulated on their beds to fill the lower reaches of their channel-ways.

The phenomena of non-conformity and of contemporaneous erosion compose a body of evidence that throughout the Pennsylvanian the progress of events was like that in previous and in succeeding periods of the world's history; there were foldings of the crust, there were differential elevations and subsidences and at all times much of the region was exposed to subaerial erosion.

THE DISTRIBUTION OF SEDIMENTARY ROCKS.

The Coal Measures rocks are sandstones, shales, limestones and coals, the terms being employed in the broad sense. All occur in each of the great eras and limestone seems to be wanting in only the Pocahontas or earliest stage of the Pottsville. An understanding of the geographical distribution and structural variations of these rocks should give some insight into the conditions prevailing at the time of their deposition; but determination cannot be complete, as erosion has removed the beds from a broad strip on the eastern border between the anthracite fields of Pennsylvania at the north and the Alabama line at the south. Beyond the latter, one finds on the eastern side only Pottsville beds; later formations are unrepresented; it is more than possible that they never were represented.

Pocahontas deposits occupied an area on the eastern side, very narrow at first but widening gradually toward the west until the close of the stage, attaining the greatest width near the Tennessee-Virginia

line. Whether or not they extended across Tennessee into Alabama cannot be determined by the stratigrapher, the palæobotanist must answer the question; but one can hardly resist the *a priori* conclusion, whatever that may be worth, that the Pocahontas did extend across Alabama and around to the southwestern outlet, as no outlet westward for the waters of the eastern valley appears in Virginia and Tennessee, and there seems to be not the slightest reason for supposing an eastern outlet anywhere to the Atlantic. The New River area is much greater, embracing the southern and middle anthracite fields at the north, where the western limit is well defined. In the bituminous region, the eastern outcrop is continuous from the northern limit in West Virginia into Alabama, where the formation is recognizable throughout the whole field; northward, on the westerly side of Alleghania, it occupies a broad area to the northern border of Kentucky whence it extends in a narrow strip almost to Lake Erie. The Beaver, at its close, evidently covered the whole basin from the northern border southward to central Tennessee; beyond that line it has been removed by erosion for about 75 miles and it is not reached again until one is well south from the northern line of Alabama. The stratigrapher cannot make correlation of horizons there, but the presence of Beaver seems established beyond doubt.

The formations of the Athens are recognizable in the anthracite fields as well as throughout the bituminous region southward into Kentucky and West Virginia; how extensively they were represented in Tennessee is undetermined. The Wheeling and Dunkard deposits, of less original extent and confined to the northern part of the bituminous region, can be studied not only by means of the many recorded exposed sections, but also by means of many hundreds of oil-well records, which make clear the conditions as they existed in the deeper portions of the region.

The Sandstones.—Stratigraphers have asserted many times that sandstones are of very little worth as horizons. It is true that those deposits exhibit abrupt changes in structure and composition, both laterally and vertically; and it is equally true that, in not a few

cases, sandstones, due to filling of valleys and occupying restricted areas, may be misleading. Yet examination of broad areas proves that many sandstones are of great geographical extent, though often interrupted and sometimes assuming the form of immense lentils embedded in shale. In a general way, one may consider the variations as alike in all; at one locality, the mass may be fine, coarse or even pebbly to conglomerate in its different layers; at another, it may be wholly fine, coarse or pebbly; while at a third, it may be represented by more or less argillaceous shale. It may be massive, irregularly bedded or shaly and the change in structure or composition may be abrupt or almost imperceptible. There would appear to be no system in these variations; yet it may prove worth the pains to seek some explanation of the conditions, for though the quest may fail of complete success, one is likely to gather suggestions by the way, which may prove of service in other directions. Four sandstones have been selected for study: Bonair of the New River, Homewood of the Beaver, Pittsburgh of the Monongahela and Waynesburg of the Washington. But in considering these, one must make comparison with others.

The Bonair sandstone of M. R. Campbell, midway in the New River formation, can be followed from its northern termination in West Virginia, along the eastern outcrop, and from northern Tennessee, on the western, almost continuously into the southeastern basins of Alabama. The eastern and western prongs on the sides of Alleghania unite across that old ridge in central Tennessee, whence the rock spreads as a sheet throughout the coal area of southern Tennessee and of Alabama. The northern limit on the western side, in the Ohio basin of Schuchert, is very near the northern line of Tennessee where it is without pebbles; but within less than 20 miles southward it becomes notably a pebble rock; at 12 miles east from the latter place it is described as 55 feet of "conglomerate and sand stone" and a similar description is given for a section at 25 miles south from the last; but at 25 miles south-southwest, the Bonair is a mass of conglomerate with shale, and the rock is still coarser at a few miles southeast, on the eastern outcrop near the Alabama line. At a few places, the western outcrop swings several miles toward the west, approaching the border of deposit, and shows another type

of change. In Putnam county, the sandstone is very thin, with an unusual thickness of shale above and below it, the greater part of the mass having been replaced with shale; in Warren county, pebbles seem to be wanting and the rock is merely a cross-bedded sandstone. Where the mass passes under cover on the east side of this area, it is much less coarse than along the outcrop line.⁴²

On the eastern side of the coal area in Tennessee, the Bonair is largely pebble rock near the Alabama line, but at 20 miles north, it is sandstone, 65 to 75 feet thick, and this is its character for several miles. But, at 32 miles from the Alabama line, it is a mass of "conglomerate and massive sandstone," a condition prevailing northward at all exposures for about 30 miles; but, thence until near the Virginia line, the sections show only sandstone with some shale, there being apparently no pebble rock. The outcrop on this side trends considerably east of north, so that, near the Virginia line, one is 75 miles away from the western outcrop; yet the rock is without pebbles, whereas on the western side, in the Ohio basin, it is coarse and pebbly. The probable equivalent in southwest Virginia is for the most part loosely cemented sandstone with shale, changing to shaly sandstone toward the west but becoming a great sandstone with some pebbles at a few miles farther along the extreme easterly outcrop. Beyond New River in West Virginia, the Bonair horizon has been recognized for about 40 miles; ordinarily the rock is merely a sandstone, but, toward the northern termination, the outcrop is carried eastward and, at the extreme exposure, one finds the rock very coarse with quartz pebbles abundant and at times with diameter of 2 inches. Westwardly it decreases rapidly and within a few miles thins out against the slope of Alleghania.⁴³

Returning to the south and going southeastwardly in Alabama, one finds striking changes in the Bonair. In that state are several troughs, separated by narrow intervals and lying southeast from the continuous area, followed thus far, while that area extends unbroken

⁴² This summary is based on observations by J. M. Safford, C. W. Hayes, M. R. Campbell, recorded in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 15, 1904, pp. 114-126, 136-146.

⁴³ For the observations of Campbell, Hayes, F. H. Bradley, Safford, I. C. White and Stevenson, see *Bull. Geol. Soc. Amer.*, as above, pp. 136-190.

into the Warrior coal field. Raccoon mountain, a prong from the continuous area, shows on its westerly side the Bonair sandstone, 30 to 50 feet thick and in great part pebbly; but on the easterly side the thickness is 75 to 80 feet and the rock is almost wholly pebbles. On Blount mountain, the southern prolongation of the east side of Raccoon, the mass thickens southwardly along the strike to 100 and finally, as estimated, to 500 feet. It is not pebbly throughout, but in portions where conglomerate prevails, the pebbles are not cemented firmly. In the small Lookout area, the Bonair is 50 to 60 feet thick and very coarse near the Georgia line, but at 10 miles southwardly it is a moderately coarse sandstone. The Cahaba basin is only a short distance southeast from the strike-line of the Lookout, but the interval sufficed for great change and the Bonair horizon is marked by more than 600 feet of conglomerate, sandstone and gritty shales; while in the Coosa field, only a few miles farther southeast, the rock is coarse conglomerate about 500 feet thick. The Lookout area, at the Tennessee line, is barely 30 miles from the present border of Archæan and the Coosa area is several miles nearer. The latter is not more than 30 miles from Raccoon mountain in direction of dip. The rock is coarsest in Coosa, less so in Cahaba, less in Blount and still less in Raccoon; in the Warrior basin beyond, one finds the Bonair persistent almost to the western boundary of Alabama, but losing its coarseness and at length replaced more or less with shale.⁴⁴

Certain features of the Bonair should be emphasized. Where the western border of its area is approached in Alabama and at a few localities in central and northern Tennessee, the rock is less thick, with few pebbles, a more or less cross-bedded sandstone, at times replaced in part with shale. Along the western outcrop in Tennessee, aside from the extreme western localities, the rock consists, in considerable spaces, very largely of pebbles, while in other and intervening considerable spaces, it is merely a sandstone with layers of pebbly rock varying in number and thickness in different localities. And this condition exists where the Bonair passes under cover toward the east, as also where the equivalent area is cut by

⁴⁴ For the observations by H. McCalley, A. M. Gibson, Safford, Hayes and J. Squire, see as above, pp. 126-136.

the outcrop farther south. But where the horizon is exposed on the eastern outcrop near the Alabama line, and thence northward for miles the rock is pebbly with layers of conglomerate: while farther north, for an equally long distance, the rock is sandstone, rarely containing conglomerate layers but not unfrequently layers of shale. It must be noted that spaces in which conglomerate features prevail throughout the mass appear, from the descriptions, to be narrow and that bands of conglomerate pass out from them into the sandstone on both sides. At times the conglomerate is as a lentil in the sandstone. The features are the same in the southeastern basins of Alabama, for there the conglomerate shows vertical as well as horizontal passage into finer material.

The other great sandstones of the New River show similar variations, but conditions in successive beds are rarely the same in any locality. The Etna sandstone, below the Bonair, can be recognized in an almost equally great area; it varies in texture as does the upper sandstone; but it is often comparatively fine-grained and without pebbles where the Bonair is very coarse, and very coarse where the Bonair is not coarse. The sandstones were formed after the same manner, though the local conditions varied.

The Homewood sandstone of I. C. White is the closing deposit of the Pottsville, apparently the first bed to cover the whole extent of Alleghania. It was recognized in the anthracite fields by its lithological character and the identification was made complete by D. White's study of the plants, which proves that it underlies the first beds carrying an Allegheny flora. It can be followed in the bituminous region from northwestern Pennsylvania into northern Tennessee, beyond which to central Alabama it has been removed by erosion. Its equivalent in Alabama has not been determined.

The Homewood is, for the most part, a coarse conglomerate in the southern and middle anthracite fields, becoming less coarse in the latter, but even there containing pebbles up to the size of a hen's egg. The coarseness decreases in the northern field and at the easterly end the deposit is a sandstone with layers of "pea conglomerate." The small Broad Top area, which may be regarded as on the line of strike with the northern field, shows only a moderately coarse sandstone with occasional pebbles, rarely one half inch in diameter.

Some insignificant fragments, containing a score or two of square miles, remain, at the northwest, between the northern field and the bituminous region. In those, the rock is for the most part a massive conglomerate, with occasional fragments as large as a walnut, but there is little of fine material, showing marked selection by the depositing agent. Along the Allegheny front, the Homewood is by no means a coarse rock at the north in Clinton but in Center, the next county south, it has one part exceedingly coarse, with mostly quartz pebbles, at times as large as a hen's egg. In Blair, no pebbles are reported but in Bedford there are some pebbly layers; thence southward to the Potomac, it seems to be merely a massive sandstone. The only unexpected feature here is the presence of large pebbles in Center county.

This sandstone is exposed frequently in a strip, 75 miles wide, west from the Allegheny crest. On the northern border in Bradford county, it contains occasional layers of pea conglomerate, but those disappear quickly toward the west so that pebbles are few in the adjoining county. Southward to the Conemaugh River, half way to the southern boundary of the state, there is at most localities only sandstone, sometimes broken by shales; but in Clearfield county, midway in this strip, and just west from the Center county area, very coarse rock is reported at this horizon, there being layers of conglomerate with quartz pebbles often as large as a hen's egg. The deposit is in an irregular narrow space, extending half way across the county and the coarse material is wanting on the western border. This marks the eroded crest of Alleghania and the Homewood rests on what seems to be the Logan or lowest deposit of the Mississippian. South from the Conemaugh, the Homewood is variable; at one locality it has 70 feet of sandstone while at 4 miles away the interval is filled almost wholly by shale. But for the most part, from the Conemaugh to the Baltimore and Ohio railroad in West Virginia, the rock is a moderately coarse sandstone with occasional pebbles, seldom larger than a pea.

Farther west in Pennsylvania, the Homewood is sandstone at all localities along the northern border, varying in thickness from 15 to 70 feet at expense of underlying beds. Pebbly layers occur at times but the pebbles are small; southward, in Clarion and

Venango, it is coarse to somewhat pebbly sandstone at some localities but shaly at others; there, as in northern Butler, it varies from 15 to 80 feet, always at expense of underlying beds. In Mercer it is from 70 to 30 feet, being thickest at the north where it varies from good building stone to pebbly rock, while farther south in Lawrence the horizon is marked by shale to coarse pebbly rock, but in most of the county it seems to be represented by fine material. This is within the drift covered area and the exposures are not sufficient for determining the relations of the pebbly areas.⁴⁵

The change beginning in western Pennsylvania becomes very marked in Ohio. Along the northern and western outcrop the deposit is wholly indefinite, being mostly shale, sandy to argillaceous, with occasionally some shaly sandstone. So great is the contrast between these and the eastern conditions, that for a generation the relations between the Ohio and the Pennsylvania Measures were ground for very serious dispute. The Homewood is nowhere in Ohio an important member of the section. In Kentucky the interval is filled with characterless shale and sandstone. In northern Tennessee, the section extends to and above the Homewood horizon and without doubt one of the important sandstones is equivalent to the Homewood. On the eastern side in Virginia and West Virginia, the horizon is distinct, though at some localities, north from New River in the latter state, one cannot differentiate the Homewood from underlying beds. But the rock underlying the Allegheny flora is usually a well-marked sandstone for at least 40 miles north from that river; there, however, the outcrop turns toward the east and the rock becomes pebbly. In Tucker county, the last eastward exposure shows 55 feet of rock, the lower portion for 40 feet being massive conglomerate. Westwardly from the outcrop, the rock rapidly becomes less coarse and, within a score of miles, it is shaly sandstone or shale.

The Homewood is buried deeply in the greater part of West Virginia, north from the Kanawha River, as well as in eastern Ohio

⁴⁵ The observations by F. Platt, W. G. Platt, I. C. White, H. M. Chance, E. V. d'Inwilliers and Stevenson are recorded in "Carboniferous of the Appalachian Basin," as above, pp. 42-70. The reader will find an admirable summary of earlier observations by H. D. Rogers, J. D. Whelpley, R. M. S. Jackson, P. W. Shaeffer and J. P. Lesley in H. D. Rogers's "The Geology of Pennsylvania," 1858, Vol. II., pp. 21-26.

and southwestern Pennsylvania. For that area one can depend only on the series of oil-well records, chiefly those collected and collated by I. C. White. Where exposed along the eastern and southern border in West Virginia, the horizon is marked usually by a sandstone, seldom very coarse and sometimes shaly. In the interior or deep part of the basin, where the coal beds are indefinite, it is not always easy to carry the section, though the drillers find no difficulty in identifying the horizon. At the north, in the "Panhandle," the Homewood seems to be represented in most cases by shale, sandstone occurring, for the most part, as filling valleys. So also in Washington of Pennsylvania and Wetzel of West Virginia the interval is frequently filled with shale. The horizon is indefinite throughout; in many records it is marked by sandstone, in many others by shale. There is no room for doubt that, in considerable spaces, sandy shale was consolidated into sandstone; but careful tabulation has convinced the writer that, in not a few of the long lines of records reporting sandstone, one has merely the records of subaerial valleys eroded not long before or after the close of the Beaver.

The Homewood material came from all sides of the basin. On the eastern side, the quartz pebbles from the old Appalachian land decrease rapidly in size westward; the strip of coarse rock in Center and Clearfield counties of Pennsylvania with possibly related patches in Jefferson and Elk counties as well as a similar strip near the northern outcrop may be records of valleys heading east from the present Allegheny front. The materials at the west came clearly from the low slopes of Cincinnati and from the north. The very marked variations in thickness, always at the expense of underlying beds, leads one to suppose that the irregular crustal movements, so characteristic of the Allegheny, had already begun.

The Allegheny was a time of great irregularity of deposition, there being abundant evidence of subaerial erosion at many places and at different horizons; and the old valleys have been filled, in most instances, with more or less pebbly sandstone. At the southeast the formation is marked by coarse massive sandstones extending into the Conemaugh, which cross West Virginia in southwest direction; but they lose their coarseness quickly toward the northwest. The sandstones of this formation as well as those of the Conemaugh

become less important in Ohio, where occasionally they contain some small pebbles.

The Pittsburgh sandstone of H. D. Rogers, the first great inorganic deposit of the Monongahela, is separated from the underlying Pittsburgh coal bed by a shale varying much in thickness—often wanting. The distribution and characteristics of this sandstone show that great changes had taken place since the close of the Beaver, even since the close of the Allegheny. The area as it now exists is restricted to the southwest corner of Pennsylvania, a narrow strip of eastern Ohio and north central West Virginia. Outliers in synclinals at the east as far as the Potomac area of Maryland and West Virginia may be regarded as evidence that the eastern border of the deposit was not more than 75 miles west from the Archæan of Appalachia.

The horizon is marked by shaly sandstone and sandy shale in the outliers, but when one, going westward, reaches the continuous area in Westmoreland and Fayette of Pennsylvania, he finds commonly a hard massive sandstone, occasionally changing into shaly sandstone. I. C. White has followed this in West Virginia to the Kanawha River and thence along the southern outcrop into Ohio. There, as in Pennsylvania, the rock is often coarse, at times forms cliffs, is feldspathic, seldom pebbly, except at the southwest, and the pebbles are always small. Within little more than a score of miles from the eastern outcrop this rock disappears, permitting, in southern Pennsylvania and adjacent part of West Virginia, the Redstone limestone to rest on the shale overlying the Pittsburgh coal. The change is very abrupt. At Morgantown, West Virginia, this sandstone, 40 feet thick on the east side of the Monongahela River, is absent on the west side and its interval has disappeared from the section. In Pennsylvania, this sandstone extends southwardly from the northern outcrop 60 or 70 miles but it thins westwardly so that in the West Virginia "Panhandle" it is absent. Its continuity along the northern outcrop is broken and a gap of perhaps 25 miles is in the panhandle and Jefferson county of Ohio, but the rock reappears in Harrison county of the latter state, where it is 40 to 70 feet thick. Thence it has been followed to southern Ohio, where it is continuous with the southern border as determined by I. C. White in West Virginia.

Whether or not the sandstone existed in the northern area, where no trace remains, cannot be determined. Erosion has removed the whole section in the space where the sandstone should be present; but it seems probable that the sandstone was not wholly continuous, as an outlying exposure in Jefferson county of Ohio shows only shale. Aside from this gap at the northwest, the sandstone is practically continuous around the whole Monongahela area; it is often coarse, sometimes shaly, at others massive, is seldom pebbly, except at the southwest, where it has conglomerate layers with pebbles up to an inch in diameter; occasionally it is replaced with sandy, even argillaceous shale. It thins away rapidly toward the center of the area; well records in the deeper part of West Virginia frequently note sandy shale or sandstone, just above the Pittsburgh coal bed, but, in view of the disappearance of the deposit at the border of the area, these occurrences cannot be taken as its equivalent.

The material came from all sides of the basin, as is clear from the distribution, but on the western and southwestern outcrop the rock is coarse, at times even conglomerate, whereas the earlier sandstones are fine grained. If the conglomeratic sandstones at top of the New River were exposed to erosion at this time, one would have no difficulty in determining the source of the material. That those sandstones were exposed appears the more probable when one considers that the area of deposition had become greatly restricted. The coarse rocks of the Logan in southern Ohio, long exposed, may have yielded some of the material, but Hyde's description of those deposits makes clear that they were not the source of the larger pebbles. The character of the material along the eastern outcrop suggests that it had come from a distance and had been rehandled many times.

The higher sandstones of the Monongahela in Pennsylvania are mostly of small areal extent and are present for the most part on the borders of the Monongahela area; but in West Virginia they are thicker and more extended. Yet there as in Pennsylvania they decrease toward the center of the area and are replaced with finer deposits.

The Waynesburg sandstone, separated by a thin deposit of shale

from the underlying Waynesburg coal bed, is the first important member of the Washington formation.

This sandstone was not seen in the Broad Top basin of Pennsylvania but it is present and 45 feet thick in the Potomac region of western Maryland. The horizon is not reached in other outlying patches of the higher coals and only occasional fragments remain on the extreme east side of the continuous Washington area. These, separated by intervals of several miles, consist of coarse sandstone containing pebbles of small size, scattered irregularly throughout the mass. At six or eight miles farther west, the rock is continuous. At the northern outcrop it is from 25 to 50 feet thick, consisting of sandy shale to laminated sometimes massive sandstone; thence to the West Virginia line the same character persists, though the lower part tends to become massive and the thickness increases at times to 75 feet, but not at expense of underlying deposits. Oil well records show that in the extreme southwest corner of Pennsylvania this "Bluff Sand" of the drillers persists with thickness of 55 to 65 feet. Westwardly into the West Virginia panhandle the deposit is somewhat thinner, less well consolidated, while the lower portion occasionally contains pebbly layers. Southwardly in West Virginia, I. C. White has followed the Waynesburg sandstone along the eastern and southern outcrop into Ohio. It is 50 to 75 feet thick and for long distances forms rugged cliffs. At the southeast, on the Pocatalico River, he found it massive, very coarse and pebbly. In the interior of West Virginia, this sandstone is persistent in all well records southward to some distance beyond the Baltimore and Ohio main line and westward to the middle line of Doddridge and Wetzel counties. Farther west, it is seldom enough consolidated to be called "sandstone" in the drillers' record. Farther south, the records can hardly be compared; typical horizons are lacking in a considerable area and the region is marked by notable irregularity in intervals.

Following the northern border, one finds this sandstone 50 feet thick in Jefferson, Harrison and Belmont counties of Ohio and it is persistent thence along the western outcrop. In Morgan county it contains layers of pebble rock; in western Washington it is 50 feet of sandstone with no pebbles reported, while in the southeastern

part of that county a massive pebble rock extends at times to almost 100 feet above the Waynesburg coal bed. Within the oil region of the same county the Waynesburg is represented by 28 feet of pebble-rock. In Athens and Meigs it is a coarse sandstone, at times a pebble-rock in the latter county, where it becomes continuous with the southern outcrop in West Virginia.

The Waynesburg sandstone can be traced almost uninterruptedly around the Washington area; it extends many miles farther south and west into the interior than does the Pittsburgh sandstone; on the western outcrop it is coarser than that deposit and shows the pebbly layers much farther northward, while it extends many miles farther eastward. The north-south area, in which it is not recognizable distinctly by comparison of drillers' records, is not more than 50 miles wide and 100 miles long. The rock varies in structure, often abruptly, so that within a very short distance the topography may change from rude to gentle outlines; but the variations are like those of other sandstones. The conglomerate bands and occasional areas of conglomerate rock on the western outcrop indicate that the source of the Pittsburgh pebbles had become more available. The presence of conglomerate and very coarse sandstone at Pocatalico on the south-east outcrop certainly indicates a source of pebbles not far away, but the occurrence may indicate also a buried valley.

The higher sandstones of the Washington are very indefinite at the north, where the changes are so frequent that the beds must be taken as lentils of no great extent; but the Marietta sandstones of I. C. White are in the southwestern part of the area, where, in earlier times, only irregular deposits existed. This group was named because quarried near Marietta on the Ohio River in Washington county of Ohio; but it is recognizable for scores of miles in each direction within the Central area, where red shales are the striking feature, where the earlier sandstones have disappeared to be replaced with the red shale containing lentils of sandstone. They indicate extensive exposures of coarse rock at the southwest and west.

Sandstones of the Greene or closing formation of the Pennsylvanian tell even more clearly of the changing conditions. The great Fish Creek and Gilmore sandstones near the top of the formation occupy the middle line of the area from their northern outcrop

to their last exposure in West Virginia. They are coarse, loosely cemented and weather into caverns. The area in which they remain is too narrow to afford information respecting the local conditions of deposit. Their presence along the middle line of the area, where the lower formations have little aside from fine materials, marks the approaching close of deposition in the Appalachian basin.

It is evident that the materials for these sandstones had not a common source. The Bonair, east from Alleghania, received its sand and pebbles from the east, from Appalachia; it becomes less coarse as it approaches Alleghania but beyond that ridge it is again coarse, even pebbly. The sands and pebbles of this western prong must have come from the north as did those of the still newer beds of the New River. The Homewood like the Bonair is very coarse in eastern parts of the basin but the pebbles decrease in size as well as number toward the northwest. But in much of western Pennsylvania, the rock is coarse and more or less pebbly. Here again one must look to the north for the source of coarse material; none could come even from the line of the present Allegheny mountains, for there the rock is without coarse elements except along narrow easterly-westerly lines, marking filled valleys, cut probably in the sandstone itself. The fine sands and argillaceous shales, so commonly marking the horizon in Ohio, point unmistakably to the low Cincinnati at the west as their place of origin. The sandstones of the higher formations extend successively farther toward the interior of the area of deposit, and for the most part become coarser and less firmly cemented as one ascends in the series. The area of deposit was contracting throughout and elevation along the borders permitted the streams to cut down to the coarse beds of earlier formation.

The abrupt variations in structure and composition, laterally and vertically, seem to find explanation in the phenomena of actual river deposits. River phenomena are distinct in the Bonair west from Alleghania. Along the middle line of the old channel way the rock is coarse, usually with abundant pebbles of considerable size, but on each side the coarseness diminishes so that, at the east, one finds sandstone with pebbly layers and, at the west, merely

cross-bedded sandstone with shale. Where the sandstones extend over broad areas, the conditions are less quickly apparent; but the channel-ways of streams across the often flooded plains are marked by the lines of coarse materials, while the migrations of those streams are recorded in pebbly bands at various levels, now on one, now on the other side of the more or less persistent channel-way. The form of the pebbles and of the sand grains is that due to the action of running water; the remarkable freedom from argillaceous matter characterizing so many sandstones and conglomerates could be brought about only by running water supplemented, perhaps, by the winds.

Other features of the sandstones deserve consideration.

Tree-trunks have been observed in sandstones of all ages since the Devonian. Long ago J. Hall found fragmentary stems in the Devonian of New York; Dawson reported them from rocks of the same age in Canada; Sherwood saw them in northern Pennsylvania and Newberry described forms from the Lower Devonian of Ohio. Such stems are not rare in the Upper Pocono (Logan) of Pennsylvania; they have been reported from the New River beds of Ohio, the Beaver beds of Pennsylvania, Ohio and West Virginia; the Millstone Grit of New Brunswick; the Allegheny beds of Pennsylvania and West Virginia and occasionally from sandstones of higher formations. They are characteristic of Carboniferous sandstones in other areas as well as of those of other times.⁴⁶

In fine grained sandstones one usually finds only small pieces and comminuted fragments of wood but occasionally a large almost uninjured stem has been found, resembling those sometimes dropped on overflow plains by receding floods. Large trunks are not reported from many localities but they have been seen most frequently in coarse sandstones. Hildreth saw some more than 30 feet long in a Beaver sandstone on the Kanawha River; another stem, in

⁴⁶ S. P. Hildreth, *Amer. Jour. Sci.*, Vol. XXIX., pp. 22, 37, 73, 76, 107; L. Lesquereux, *Geology of Pennsylvania*, 1858, Vol. II., p. 840; F. Platt, *Sec. Geol. Surv. Penn.*, Rep. H, 1874, p. 23; A. Sherwood, *ibid.*, Rep. G, 1878, pp. 21, 38-40; I. C. White, *ibid.*, Rep. Q, 1878, p. 203; Rep. Q2, 1879, p. 137; U. S. Geol. Surv. W. of 100th Mer., Vol. III., Supp. 1881, p. 196.

probably an Allegheny sandstone on the same river, was not less than 50 feet long. As a rule, the fragments mentioned by observers are much smaller, rarely exceeding 7 or 8 feet; they are broken at the ends, without trace of root or branch; some appear to have retained their bark when entombed, but, in a great proportion of the instances, the rock contains indeterminate casts of the stem with scattered impressions of the bark. The battered fragments are unquestionably those of floating wood which had long endured exposure, while those which show no injury, aside from loss of roots and branches, were probably prostrate stems carried from a flooded plain. There seems to be no general distribution of stems in any sandstone; in each case the occurrence is noted by the observer as an interesting local phenomenon. If the materials had been carried out to a great basin, where the plant remains could float until water-logged, there would have been a general distribution over a wide area, such as that described by A. Agassiz as existing off the coast of Lower California and in the Caribbean; but the condition is wholly different in the Coal Measures sandstones and bears close resemblance to that observed in the rivers of this day, where logs and undermined trees are stranded on the banks or on gravelly islands to be attacked by successive floods and, after removal of the fragile portions, to be buried in the accumulating deposits.

The less injured fragments, retaining the bark, differ much from those found in coal beds in that commonly they are but slightly deformed by pressure—and this in spite of the fact that ordinarily they are merely casts surrounded by brilliant coal from the bark. Prostrate trunks in coal beds are flattened, while stumps in the coal retain the wood, converted into mineral charcoal and surrounded by the brilliant coal. It may be that the uncompressed stems were those thrown upon sandy bars to decay slowly and to have the interior replaced with sand, while the battered fragments may have remained long above reach of ordinary floods, to be swept away only after loss of the interior. But in any event, one must recognize that the small quantity of the wood found in sandstones is a very important matter; the sandstones and con-

glomerates mark times when activity of denuding agencies was greatly increased, when the destructive effect of floods upon vegetation ought to be most marked.

Surface features of sandstones received little attention from earlier observers in the Appalachian basin. Ripple marks, sun cracks and rain prints seem to have been regarded as mere common-places and the recorded observations are merely incidental. Observers in recent years have recognized the importance of these surface markings.

The ripple or wave marks on some Silurian sandstones attracted attention long ago, as they are exposed in broad spaces and, for the same reason, occasional references are to be found to similar markings on some Devonian beds. The earliest note respecting their occurrence in Carboniferous rocks is that by Rogers,⁴⁷ who says of the sandstones of Formation X that "beautiful ripple markings are often met with on the surface of the large slabs of the finer of these sandstones." This formation is equivalent to the Upper Pocono of Pennsylvania; and the observation is important because it was made in the area where the earliest coal beds were formed. The rocks are in the lowest division of the Mississippian or Lower Carboniferous.

H. D. Rogers, J. P. Lesley, B. Halberstadt and G. P. Grimsley have recorded observations of wave marks and mud cracks in the Mauch Chunk of Pennsylvania and West Virginia; and J. Barrell has discussed their importance in a memoir to which reference will be made on another page.

Scattered observations show that such surface markings are of common occurrence in Pottsville rocks.⁴⁸ Smith obtained a fine slab of sun-cracked sandstone of New River age near Huntsville, Alabama; Ashley reports sun cracks in New River sandstones of

⁴⁷ W. B. Rogers, "Report of the Geological Survey of the State of Virginia for 1837," reprint, Boston, 1884, p. 183.

⁴⁸ E. A. Smith, letter of December 23, 1911; G. H. Ashley, letter of October 24, 1911; J. W. Foster, cited by J. P. Lesley in "Manual of Coal and its Topography," Philadelphia, 1856, p. 105; I. C. White, Sec. Geol. Surv. Penn., Rep. Q3, 1880, pp. 194, 195.

Cumberland and Rhea counties, Tennessee, the former being on the western, the latter on the eastern outcrop; Foster described a coarse sandstone on Licking River, Ohio, with ripple marks and indistinct fucoids, the latter being most probably casts of sun cracks. White reports the flags at a quarry in Mercer county of Pennsylvania as showing both ripple marks and rain prints.

The writer finds no record of ripple marks or sun cracks on sandstones of the Allegheny. Several correspondents assert that they have seen them frequently but cannot remember the localities as no entries were made in the note books. Condit⁴⁹ observed excellent examples in the Conemaugh of Ohio at 15 feet below the Pittsburgh coal bed and at 60 feet below the Ames limestone. Stevenson saw in Fayette county of Pennsylvania a Conemaugh sandstone of which the layers, exposed in a quarry, are covered with irregular ripple marks, closely resembling those made by winds on dunes or sand plains. A laminated sandstone at 57 feet below the Pittsburgh coal, in Allegheny county, is ripple marked on many of the surfaces. In Fayette county, the shales overlying the Pittsburgh coal frequently contain thin layers of ripple marked sandstone and in Greene county the Pittsburgh sandstone shows the irregular trails known as *Spirophyton*. In Fayette and Westmoreland counties, ripple-marked surfaces characterize the Waynesburg sandstone at the base of the Washington formation. The uniform testimony of those who have studied the Appalachian basin is that ripple marks and sun cracks are familiar phenomena in the Coal Measures sandstones or in the clayey films separating the layers.

Footprints in sandstone have been reported from but one locality. King long ago announced the discovery and the occurrence was confirmed sometime later when he and Lyell⁵⁰ studied the rock together. The quarry in a Conemaugh sandstone was about 5 miles southeast from Greensburg, Westmoreland county, Pennsylvania.

⁴⁹ D. D. Condit, letter of February 14, 1912; J. J. Stevenson, Sec. Geol. Surv. Penn., Rep. K, 1876, pp. 99, 200, 208, 309; Rep. KK, 1877, pp. 31, 208.

⁵⁰ C. Lyell, "On Footmarks Discovered in the Coal Measures of Pennsylvania," *Quart. Journ. Geol. Soc.*, Vol. II., 1846, pp. 417-420; Vol. VII., 1851, p. 244.

The sandstone, in thin flags used for paving, is divided by laminæ of unctuous clay, which received and retained the impressions. Twenty-three footprints were obtained, all of them on the under surface of slabs, casts in relief of impressions made upon the clay. There were also casts of shrinkage cracks in the clay, made after the footprints were formed. Rain prints were observed on the slabs which Lyell took to England.

The sandstones in other coal fields have similar markings; Ashley has described ripple-marked sandstones in Indiana and J. A. Udden has found them in Illinois. Dawson,⁵¹ who recognized the importance of recording all observations, has noted the occurrence of ripple and rain marks as well as of footprints at many localities within the Acadian areas. A sandstone in South Joggins shows distinct rain and footprints; on the shore of Northumberland strait, where the strike coincides with direction of the shore, great surfaces are exposed with ripple marks and worm trails. In 1842, he found, near Tatamagouche, footprints on a rippled surface and in 1843 he discovered two other series of prints, one of which was somewhat defaced by rain marks. Many beds within this region have ripples, rain marks, worm trails and sun cracks in clay laminæ within the sandstones. Lyell summarized the information respecting them. Hull has recorded similar conditions in Lancashire of England and Miller has described the footprints at Dalkeith in Scotland.⁵² Similar markings are reported from almost all the large coal areas, and they are characteristic of sandstones containing laminæ of clay on which the markings were impressed.

Many authors have noted the "Vegetable soils" or "Ancient soils" observed in sandstone. These may be marked by local deposits of coal or by erect trees *in situ*, with or without traces of coal around the roots.

⁵¹ J. W. Dawson, "Acadian Geology," 2d ed., 1868, pp. 167, 215, 217, 325, 328, 355, 357, 410; Supplement, 1878, pp. 62, 64.

⁵² C. Lyell, "On Fossil Rainmarks of the Recent, Triassic and Carboniferous Periods," *Quart. Journ. Geol. Soc.*, Vol. VII., p. 244; E. Hull, "Geology of the Country around Wigan," 2d ed., Mem. Geol. Surv. Great Britain, 1862, pp. 9, 10.

The official reports note the not infrequent occurrence of coal patches in sandstone, some of them only a yard but others several rods long and wide. Without doubt, not a few of these are merely blocks of vegetable matter removed by sand-laden streams during change of channel-way; but others, such as that described by I. C. White,⁵³ are unquestionably *in situ*. In this case, the deposit is of impure cannel, 5 feet thick where opened, but disappearing in all directions within a few rods. It evidently marks the site of a shallow pond on the sandy surface, which was filled with sapropel material. It is probable that a similar explanation applies in many other cases, as impure cannel is the usual material.

Not many references to erect trees in sandstone are to be found in reports on the Appalachian basin; such trees, for the most part, are rooted in shales. Lesquereux⁵⁴ has mentioned the occurrence of a forest of *Sigillaria* and *Calamites* in sandstone over the great coal bed at Carbondale in the Northern Anthracite field. This seems to be the only recorded instance where the relations are clear; but Dawson⁵⁵ observed several ancient soils in sandstone. His Division II., 650 feet thick, has two old soils with erect trees; Division III., 2,134 feet thick, has many with erect trees, the old soils being in most cases very thin shale enclosed in sandstone. At one locality this thin shale bears erect *Calamites* and shows rain prints as well as footprints of batrachians; another, somewhat lower, with erect stems, has yielded several species of batrachians as well as remains of insects and land mollusks; at another, the sandstone cliff shows trees as pillars of sandstone and with them are associated *Calamites*, all vertical to the bed, which is inclined at 19 degrees. Here the sandy flat, supporting the trees, was inundated and covered with sand; in time, the trunks rotted and were broken off to be covered by the increasing deposit, which filled the interior of the decaying stem. At another horizon, one stem rises 4 feet and is surrounded by sandstone and the succeeding shale, but another reaches only to the top of the sandstone. On this sandstone there

⁵³ I. C. White, Sec. Geol. Surv. Penn., Rep. Q, 1878, p. 202.

⁵⁴ L. Lesquereux, "Geology of Pennsylvania," 1858, Vol. II., p. 840.

⁵⁵ J. W. Dawson, "Acadian Geology," pp. 156-178.

grew a forest of *Calamites*, which, in their turn, were surrounded by the mud, which reaches to the top of the larger *Sigillaria*. This growth of *Calamites* on sand, which had buried the *Sigillaria*, recalls the conditions at Topeka, Kansas, already described, where during a great flood the young trees of a large nursery were buried by sand, on which a dense growth of cottonwoods developed within a few weeks. The conditions recall also those described by Russell on the Yahtse River in Alaska. The trees were killed, not broken by the mass of gravels; the trunks decayed, some were broken off by the wind and the stumps were buried under new material brought down by the river, but others remained, at the time of Russell's examination, projecting many feet above the surface.

The evidence all points in one direction. The buried channels, the cross-bedding reported at many localities and the rounded pebbles indicate river not shore deposit. Plants buried *in situ* by inundation, the ripple-marked and sun-cracked surfaces, the rain prints, the footprints of batrachians, the pool-like accumulations of vegetable matter, the absence of marine fossils and the distribution of the coarser materials make up, altogether, a mass of evidence which it is difficult if not impossible to controvert. The sandstones were great flats, subject to inundation by the rivers to which they owed their origin. There appears to be no evidence to support the supposition that they are either shore or deepwater deposits.

The Shales.—Coal Measures shales vary in structure from merely compacted muds to finely or coarsely laminated beds; in composition from fine clay to sand or impure limestone; in color from almost white to black, the latter often passing to cannel or even to ordinary coal. Thick deposits of shale frequently hold lenses of sandstone and similar lenses of shale occur in sandstone. Some shales are rich in remains of a marine, a brackish water or of a freshwater fauna; others are crowded with impressions of land plants, retaining the most delicate markings of all parts; others have only indistinct plant remains, with which a marine fauna sometimes occurs; others still, of notable thickness and area, have rare and mostly obscure traces of either vegetable or animal life.

Sandstone predominates in the Pottsville but in later formations shale is a characteristic feature. This is true of the anthracite area almost equally with the bituminous region, as appears from the sections and drill-hole records published by the Pennsylvania survey.⁵⁶

The anthracite region, including the broad eroded spaces between the coal fields, is about 70 by 100 miles, but the coal area, which has escaped erosion, is considerably less than 500 square miles. The Pottsville deposits are almost wholly sandstones or conglomerates except locally in the Eastern Middle, where the Beaver shows here and there thick beds of shale, 22 to 42 feet thick. Conditions changed gradually after the beginning of the Athens, so that above the Mammoth coal bed, identifiable with comparative certainty throughout much of the area, one finds abundance of shale. At the northeast in the Southern field, one section has 194 feet of shale in a total of 218; another has one bed, 64 feet, and three thinner beds in 257 feet; midway in the field, some sections show nearly one half shale in 900 feet above the Mammoth. There is much variation in thickness and in position of the shale beds and none is persistent in all the sections. In the Western Middle, the thickest bed at the easterly end is but 40 feet, but farther west are beds of 45 to 107 feet with others of less thickness, while at the western end shale and sandstone are often in equal thickness. The proportion of fine shale above the Mammoth is as large as in most of the bituminous region and some of the beds are thicker than any there outside of the central space in West Virginia. Farther south along the eastern border in Alabama, where only the Pottsville remains and the conglomerates are thick and coarse, one finds great beds of finer materials, though argillaceous shale seems to be comparatively unimportant.

Sandy shales are closely related in distribution to the sandstones; black or carbonaceous shales will be considered in connection

⁵⁶ The survey of the anthracite fields was planned by C. A. Ashburner and was executed under his direction. His death occurred after completion of the work but before preparation of the report. Discussion of the results was assigned to A. D. W. Smith and it is given in Vol. III. of the Final Report.

with coal beds; it is necessary here to study in detail only the red shales and to note a few matters concerning shale deposits generally.

The Red Shales.—The red and green muds and laminated sandstones of the Catskill pass gradually into the early Carboniferous in a great area within Pennsylvania and Virginia. In like manner, the red shales of the Upper Mississippian pass into the Pottsville through a transition series of sandstones, conglomerates and red to green shale beds, this feature being especially characteristic in the southern anthracite field, where the column is complete. The reds and greens of the Catskill mark a condition, which originated in southeastern New York during the Middle Devonian and spread slowly west and southwest, reaching southwestern Pennsylvania late in the Chemung, the last great division of the Devonian. The condition, whatever its cause may have been, appears to have been without relation to the character of the water; the fauna in the northern portion of the area is freshwater, but in southwestern Virginia,⁵⁷ very near the termination of the red deposits, *Spirifer disjunctus* and some other forms were obtained at the top of the formation, showing that marine conditions reached as far northward as New River and that they were not inconsistent with the deposition of red beds. The Mauch Chunk or Upper Mississippian red beds seem to have yielded no marine forms in eastern Pennsylvania, but in southern Pennsylvania and southward, the middle and lower portions are gradually replaced with the Maxville limestone, which is marine, while in western Pennsylvania the upper portion or Shenango shale has yielded marine forms in Crawford, Mercer and Fayette counties.⁵⁸ The fossils are large and they did not live amid unfavorable conditions. The shales are red in Fayette county, so that again it is evident that influx of salt water did not prevent formation of red beds. The Pennsylvanian red shales have neither the constancy nor the extent of those in the Catskill and Mauch Chunk, but they resemble the former in that the conditions favoring their formation existed at first in a small area, whence they gradually spread; they differ

⁵⁷ J. J. Stevenson, "The Chemung and Catskill on the Eastern Side of the Appalachian Basin," *Proc. A. A. A. S.*, Vol. XL., 1891, separate, p. 7.

⁵⁸ I. C. White, *Sec. Geol. Surv. Penn.*, Rep. Q4, 1881, p. 77; J. J. Stevenson, *ibid.*, Rep. KKK, 1878, p. 308.

in that after a maximum area was reached, the conditions ceased to be general, became more or less localized and the deposits were isolated, at times widely separated.

The earliest appearance of the Pennsylvanian reds is in the New River of northwestern Georgia, where two beds, 11 and 35 feet, were found, with 103 feet of variegated shale intervening.⁵⁹ No reds are reported from the Pottsville of the anthracite region and they are rare in the Allegheny, occurring only in the lower part of that formation. A bed, 32 feet thick, was found near Drifton in the Eastern Middle at 30 feet below the Buck Mountain coal bed and, near Harleigh, a thin bed underlies that coal. In the northern part of the field, a soft red sandstone is at a few feet below the Mammoth and near Harleigh a thin bed of red sandstone overlies the Buck Mountain; at a few miles west, in the Western Middle, some thin streaks of red shale exist between the Buck Mountain and the Mammoth. These are all within a narrow north and south space and must have been brought down from the Alleghania slope.

Red shale first appears in the bituminous region during the latter part of the Allegheny. The most southerly locality is in Boyd county of Kentucky, where 18 feet of green and red shale were seen near the top of the formation. The deposit is altogether local, for measured sections and well records in adjoining counties of Ohio and West Virginia show no trace of red at this horizon. The nearest notable deposit is more than 80 miles distant toward the northeast in Washington county of Ohio, where 64 feet of red shale begins at 503 feet below the assumed place of the Pittsburgh coal bed and so extends downward to the middle of the Allegheny. There, one has reached what may be termed the Central area, in which red shales are a striking feature from the middle of the Allegheny to the close of the Pennsylvanian. This area embraces contiguous portions of Washington county of Ohio, Wood, Ritchie, Wirt, Calhoun, Roane, Jackson, Gilmer and Clay counties of West Virginia, in all not far from 3,500 square miles. Red shale in the Allegheny is reported here and there from other counties but in each case the deposit is insignificant.

⁵⁹ J. W. Spencer, "The Palæozoic Group," Geol. Surv. Georgia, 1893, p. 139.

At the beginning of the Conemaugh, one finds on the eastern and northern parts of the bituminous region an important sandstone, which becomes unimportant on the western outcrop in Ohio. In several counties within the Central area, its place is occupied by red shale. The same material occurs in occasional borings farther north near the Pennsylvania line and thin streaks are reported in a few wells north from that line; but these occurrences seem to be isolated. As one rises in the Conemaugh, he finds the areas increasing, for widely extended deposits appear below the Cambridge, the first persistent limestone of the Conemaugh. At this horizon the reds, though variable, are thick in some portions of the Central area and very irregular in others; but conditions favoring deposition of reds existed at many localities, somewhat widely separated; such deposits are reported from the Central area; from Ohio at 100 miles toward the west; from the northern counties of West Virginia; from several counties in southwestern Pennsylvania as well as from Webster county of West Virginia on the eastern outcrop. Away from the Central area, most of the deposits are thin, apparently of small area; their interrelations cannot be ascertained but there is no doubt that many of them were wholly isolated. They suffice to show that, prior to the formation of the marine Cambridge limestone, conditions favorable to deposition of red shales existed at very many localities within an area of not less than 10,000 square miles.

The Pittsburgh reds of I. C. White underlie the Ames limestone, which carries a marine fauna and is midway in the Conemaugh. This interval between the two marine limestones is marked by the greatest expansion of reds within the Appalachian basin. No trace of the deposit is seen on the eastern side of the bituminous region except in a small space within western Maryland and the adjacent part of Pennsylvania. Aside from that locality it seems to be absent along the eastern outcrop in Pennsylvania and West Virginia as well as along the western outcrop in Ohio. But in the interior portion of the bituminous region the Pittsburgh reds are present from Boyd county of Kentucky to the northern outcrop, a distance of 275 miles, and the width at times is 80 miles, giving an area of certainly not less than 17,000 square miles. The thickness varies; it becomes almost 250 feet in some localities, when the mass is continuous below

with that under the Cambridge limestone and at others where it is continuous with that above the Ames; but it is notable throughout its whole extent; even at the northern border, where no other reds are found in the Conemaugh, the Pittsburgh reds are from 30 to 50 feet thick. At the same time, it must be noted that this, like those which precede and those which follow, is in no sense a uniform deposit; the variations in thickness and character are greater than those of the sandstones and are marked by extreme irregularity. Making all allowance for defective methods of keeping the records of borings, one must recognize that a mass of red shale, 50 feet thick in one well, may be replaced, even in the Central area, with sandstone in another well only 200 feet away; that red shales alternate vertically with light gray, blue or almost white shales as well as with gray white or bluish sandstones; comparison of well records, preserved and collated by I. C. White in the West Virginia reports, leaves no room for doubt that red shales are often continuous laterally with light colored shales and sandstones, and that the transition may take place within a few rods. But in the upper portion, the Pittsburgh reds are as nearly continuous throughout the whole area as is any other deposit in the series.

The Washington reds, the "Big reds" of the drillers, follow the Ames limestone and, where that rock is absent, are often continuous with the lower deposit. This mass spreads with considerable thickness into counties adjoining the Central area but it underlies not much more than 4,000 square miles and is absent at many places even within the main red area. It seems to be wanting in most of Ohio, but a thickness of 60 feet is reported in Muskingum county at 50 miles from a locality on the Ohio River, where it is said to be 100 feet thick, no reds having been observed in the intervening space. It occurs as red shale occasionally in northern West Virginia but seems to be wanting in Pennsylvania, though its place is marked by the fine-grained Birmingham shale of that state. Its variations laterally and vertically are wholly like those of the Pittsburgh. The area of red shows more notable contraction in the upper part of the Conemaugh, but, locally, the reds were deposited in an area almost as great as that of the Pittsburgh. Thick deposits are reported from some counties within the Central area and none whatever from

others; isolated deposits are reported from 9 counties of Pennsylvania and from 6 in Ohio but there seems to be very little in the greater part of West Virginia. The total area of the reds during the later Conemaugh at any one time was less than 1,000 square miles and the deposits are widely separated. At the same time, one must note carefully that, while the deposits are usually of small superficial extent, yet the thickness of some is important.

The conditions during the Monongahela were much like those at the end of the Conemaugh but the area in which deposits were made is much less. No red is reported from Pennsylvania except a thin streak at one locality, nor is there any in the West Virginia panhandle. There is none in Ohio except near the Ohio River toward the Central area. But, as one approaches that area, the red increases and some of the beds are important. In West Virginia, there seems to be very little along the eastern side north from the Kanawha River and in the interior the occurrences are few and irregular until one comes to the Central area, where beds are many but more irregular than at any time during the Conemaugh. In Ritchie county, every foot of the section for 300 feet above the Pittsburgh coal bed is marked by red shale in some well or another; but that statement tells little respecting the conditions. The beds vary from 7 to 110 feet as measured in different records; in some borings, one finds 220 feet of red in a vertical distance of 300 feet, while in others near by the total is less than 100 feet. Similar variations are found in other counties but the maximum thickness is less. Aside from the insignificant and distant patches in Pennsylvania and Ohio, the area in which reds were deposited at various times during the Monongahela is less than 4,000 square miles and no deposit has great superficial extent.

During the Washington, local conditions favoring deposition of reds existed here and there in a much greater area; but the conditions were local. Reds are reported from three localities in Washington and two in Greene county of Pennsylvania; from six in Ohio; from a number of places in northern West Virginia; but these are all far apart and the most of them are insignificant. Only when one reaches the Central area does he find the deposits assuming importance. Even there the occurrence is indefinite: a boring in Wood

county, West Virginia, passed through two beds, 100 and 60 feet thick, but in another well, only a short distance away, the same intervals show 60 and 20 feet of red. Greater contrasts appear elsewhere, for thick deposits of red in one well are replaced with sandstone in another, less than one eighth of a mile distant.

The story is the same for the Greene. In southwestern Pennsylvania deposits, 50 to 90 feet thick, were seen, but they are local, being absent in sections four or five miles away. There are certainly some reds in the formation within the West Virginia panhandle, but the exposures do not admit of measurement. Some important deposits are reported farther south along the Ohio River but for the most part little information exists respecting them. The Greene formation in West Virginia contains nothing of economic worth and, with the exception of one persistent limestone, there are no definite horizons. There seems to be only a monotonous succession of shales and soft sandstones, all ill-exposed. But, in riding across the Central area, one recognizes at once that red shale forms no insignificant portion of the mass, though the imperfect exposures suggest that the deposits must be lenticular like those in the earlier formations.

Red shales are found in other coal basins and in later formations. Dawson⁶⁰ found them abundant in all divisions of the Coal Measures from the Millstone grit to the top and with the same features as in the Pennsylvanian of the Appalachian basin; gray and red shales alternate vertically and at times are continuous laterally. Conditions are the same in later times; lenticular deposits of red clays occur in the glacial till of Canada and of Scotland. The great Pampean formation as originally described by Darwin⁶¹ would seem to be a continuous deposit of reds covering an area almost equal to that of France; but it varies in composition as reds do elsewhere, for records of borings near Buenos Ayres show that the section consists of sand, clay and green shale. Church, to whose studies reference will be made on a later page, found that a vast area of the Plata region is covered with reddish-yellow, semiplastic argillaceous earth, contain-

⁶⁰ J. W. Dawson, "Acadian Geology," pp. 156-176.

⁶¹ C. Darwin, "Journal of Researches," New York, 1846, Vol. I., pp. 161, 164, 165; "Thickness of the Pampean Formation near Buenos Ayres," *Quart. Journ. Geol. Soc.*, Vol. XIX., 1863, pp. 68-70.

ing at times, calcareous nodules. The deposit is without pebbles and becomes increasingly sandy toward the west. The Pampean formation resembles the Pittsburgh reds. Gruner⁶² has observed that in the Loire basin, red beds are not uncommon in the sterile stage of Saint-Chamond. The deposits are found at all horizons in this formation which is from 650 to 2,600 feet thick and is the middle division of the Loire Coal Measures. In the Lancashire field of England the reds appear to be confined to the upper Coal Measures.

Dawson found abundance of ripple marks, rain and footprints in the Acadian red shales but no record of such markings on the Pennsylvanian reds has come to the writer's notice. Fossil remains, vegetable or animal, are rare, but Raymond⁶³ discovered reptilian bones in a small basin eroded in the sandstone on which the Pittsburgh red shales rest. Not infrequently the red muds contain nodules of ferruginous limestone in which are marine fossils; these abound in the Pittsburgh reds and cause much annoyance to drillers of oil wells. At one locality in West Virginia on the east side, the Pittsburgh reds are replaced with a succession of variegated shales which are exceedingly rich in marine forms, several of which pass upward into the Ames limestone; and the shales are similar at 25 miles southwest. The Pittsburgh reds, at least in part, were deposited where salt water had access. There is much to suggest similar origin for some other reds. Those below the Cambridge pass upward to that limestone as the Pittsburgh reds pass to the Ames. In considerable areas they replace the limestones and the two deposits are continuous with each other or even with the Washington reds above. The limestones are wedges in the shale as the Maxville becomes a wedge in the Mauch Chunk shales within southern Pennsylvania. The Washington reds are equivalent in position to the Birmingham shales at Pittsburgh, which Raymond, in the publication cited above, has shown to be marine. It is certain that marine conditions are in no wise antagonistic to deposition of red shale. At the same time, one must not forget that the conditions must have been very different

⁶² L. Gruner, "Bassin houiller de la Loire," Paris, 1882, p. 217.

⁶³ P. E. Raymond, "A Preliminary List of the Fauna of the Allegheny and Conemaugh Series in Western Pennsylvania," Topog. and Geol. Surv. (of Penn.), 1911, p. 89.

for isolated deposits, which are numerous and often thick. These, in many cases, were far away from any marine invasion, in regions of coal beds and freshwater limestones. Within the Central area, there is almost total absence of limestone, the coal beds are indefinite and most of those which are recognized on the borders are wholly wanting.

The origin of the red color in shales and sandstones has been sought by many students. Crosby⁶⁴ has shown that in the northern United States and Canada the soils are rarely red except when derived from a red rock; but southward from latitude 39° redness increases until, in the West Indies and South America, it becomes intense. The color is not due to the rocks, for the red deposit at the south rests on primary rocks not differing from those at the north where no red is found. He thought that the contrast is due, very probably, to climate, the dehydration of ferric hydrate and consequent change of color being caused by solar heat. In a later paper, he says that six years of additional study had led him to assign less importance to solar heat as the converting agent, but he still recognizes it as one of the important agents. Many illustrations are given, which certainly appear to go far toward fortifying his position.

Russell⁶⁵ took up the subject at a somewhat later date and reached conclusions differing from those of Crosby. The depth to which decay of rocks extends in the Appalachian region increases southwardly, becoming 100 feet in large areas, and he cites Belt as reporting that, in Nicaragua, the depth at times is 200 feet. In the great limestone valley, south from James River in Virginia, the clay remaining after solution of the limestone is red and sometimes 50 feet thick. He objects to the conclusion that climate or solar heat caused the red color, because in summer the soil is heated as strongly in the northern as in the southern states. The red beds of the Rocky

⁶⁴W. O. Crosby, "Colors of Soils," *Proc. Bost. Soc. Nat. Hist.*, Vol. XXIII., 1885, pp. 219-222; "On the Contrast in Color of Soils of High and Low Latitudes," *Amer. Geol.*, Vol. VIII., 1891, pp. 78-82.

⁶⁵I. C. Russell, "Sub-aerial Decay of Rocks," *U. S. Geol. Surv. Bull.* No. 52, 1889.

Mountains could not have become red by exposure during deposition, for the playa beds in Nevada and similar regions are creamy white, though the summer temperature reaches 110° to 120° in the shade. The red color was acquired during decomposition of the rock and consequent incrustation of the grains. Richtofen has explained the red of the Rothliegende by supposing that during the Carboniferous there was deep decay of the rock and that this material became that of the Rothliegende. Russell applies the same explanation to the great red deposits of America, which he regards as formed of debris from rocks long exposed to a warm moist atmosphere.

Beede's⁶⁶ studies are in place here. It had been ascertained that the light-colored sediments of Lower Permian in Kansas become red in Oklahoma and the same condition was observed in going northward into that state from Texas; in one instance a limestone was traced into a sandstone. Beede, following the Kansas deposits into Oklahoma, found that limestones became sandy in patches, which increased until the limestone disappeared. Farther south the sandstone becomes deep red or brown with patches of white. The limestone fauna reaches southward only a little way beyond the limit of that rock. Shales become red much farther north than do the sandstones and often have deeper color; even the limestone, at times, becomes reddened before disappearance. The sandstones vary much in thickness at expense of the shales, but the thickening is irregular, the rock is cross-bedded and often shows ripple marks. At their southern limit, the shales and sandstones dovetail into Permian conglomerate on the Arbuckle and Wichita mountains, which is formed largely of the limestone, at one time covering those mountains and even now 8,000 to 10,000 feet thick on their flanks. These limestones yield a residual red clay, while the disintegrating conglomerate yields a red sandy clay resembling that of the red beds. It would appear that the lower red beds of Oklahoma were derived from the Arbuckle-Wichita land mass and that the coloring matter is due chiefly to solution of limestones known to have been removed from the area. Beede concludes that the deposits, which are void of fossils

⁶⁶J. W. Beede, "Origin of the Sediments and Coloring Matter of the Red Beds of Oklahoma," *Science*, N. S., Vol. XXXV., 1912, pp. 348-350.

and even of carbonaceous matter, were made in very shallow turbulent water or on vast tidal beaches.

Dannenberg,⁶⁷ discussing the importance of red beds, refers to activities of changing climatic conditions as perhaps a notable agent in bringing about the contrast between the productive and the barren measures. In the productive measures, one finds constantly dark gray to black as predominating colors, due to impregnation of the whole mass with coaly substance, while the succeeding barren measures are recognizable by the red color. The Rothliegende, succeeding the Carboniferous, owes the first half of its name to this condition. But the change in color begins before the close of the Carboniferous, for the red appears as soon as conditions for coal-making end—with the entrance of red, the formation of coal beds ceases. In the Saarbruck region, reds occur in the Upper Carboniferous over the productive division. That a luxurious vegetation existed during deposition of this unproductive red shale is proved by the presence of great masses of vegetation in the Rothliegende, such as the petrified forest at Radowenz in Bohemia. Evidently not failure of vegetation but changing climatic conditions, which were unfavorable to the accumulation of plant remains, brought about the new features. The formation of red rocks and weathered products is at present a peculiarity of the torrid zone, where one finds laterite, terra rossa, etc., in which humus is unimportant. Dannenberg is inclined to think that in the Carboniferous, there were moderate, perhaps ocean climates contrasting with the succeeding hot climate of the continental Rothliegende.

Barrell,⁶⁸ who regards the Mauch Chunk (Upper Mississippian) red shales as, for by far the most part, of flood-plain origin, has published two important memoirs bearing upon the origin of the red color. In the earlier memoir he shows that the Mauch Chunk contains some impressions of plants but no trace of the carbon remains. The loss of carbon has not decolorized the shale, so that evidently

⁶⁷ A. Dannenberg, "Geologie der Steinkohlenlager," Berlin, 1910, pp. 30, 31.

⁶⁸ J. Barrell, "Origin and Significance of the Mauch Chunk Shale," *Bull. Geol. Soc. Amer.*, Vol. 18, 1907, pp. 449-476; "Relations between Climate and Terrestrial Deposits," *Journ. of Geol.*, Vol. XVI., 1908, pp. 159-190, 255-295, 363-384.

the oxidation was by free oxygen and not by that derived from ferric oxide. The discussion in the later paper covers the whole question and the author fortifies his position with the wealth of illustration that seems to leave little room for disputing his conclusions; but the discussion is so elaborate that only the final statement can be given here and the reader must be referred to the memoir itself for the detailed argument. The red color of ferruginous rocks as contrasted with the predominating yellows of alluvium is due to three coöperating causes: Spontaneous dehydration, operating to some extent at the surface in warmer regions; dehydration under great pressure and moderate temperature, nearly universal in sediments which become buried and consolidated; diffusion, operating under conditions of warmth and moisture, whether these be at the surface as in warm and humid regions or beneath the surface as may occur in any portion of the earth. By these three means, the light-colored yellow or brown muds and sands may become red shales and sandstones. The chief condition for formation of red shales and sandstones is merely the alternations of seasons of warmth and dryness with seasons of floods.

Gruner and Dannenberg lay stress upon the fact that reds occur in the sterile measures. Certainly the reds seem to have been deposited under conditions which were unfavorable to the accumulation of coal, for that is almost wanting in the central area of West Virginia; great coal beds, traceable for hundreds or even thousands of square miles, thin out to disappearance as they approach that area. At the same time one must not forget that the reds mark local, not general conditions; that they abound in the productive as well as in the less productive portions of the column. Within the Central area they are as important in the upper Allegheny and in the Monongahela as in the Conemaugh and Washington. Even in the limited Loire basin the same is true, for the reds there are practically confined to that portion of the Saint-Chamond area, which is micaceous. Whether or not a similar relation exists in the Saarbruck area, the writer has not been able to ascertain.

The distribution of Pennsylvanian red shales forbids the sup-

position that they owe their red color to any widely-acting cause. The especial localization of the deposits in the central part of the area, the lateral passage into fine shales and sandstones of wholly different color and the many isolated occurrences of small deposits seem to exclude explanations based on supposed aridity or any other general condition of climate. The shale, at times, contains small areas of coal in distinct beds, and occasionally one finds coal at the horizon of beds which are persistent around the borders. Where the mass is interrupted by other deposits, which continue to within the limits of the reds, a coal bed also at times continues from the border, though at the east only a few miles away it is wanting as the red is continuous vertically. It is certain that occasionally the conditions, favoring accumulation of coal, existed for considerable periods within the Central area of reds. No matter which hypothesis respecting the formation of coal beds be accepted, the condition of general aridity becomes inadmissible, because the existence of coal beds, great or small, is proof of humid atmosphere and dense vegetation not far away. One finds a great mass of reds at the Pittsburgh coal horizon at less than a score of miles from localities where that bed is of workable thickness; and the same statement is true respecting the Harlem and Anderson coal beds. There is every reason to suppose that in a general way the climate, in respect of rainfall, was very much as now; the direction of the winds was the same and there is no reason to suppose that, at any time during the Pennsylvanian, a mountain chain existed on the west side of the Appalachian basin. Yet alternation of wet and dry conditions, as suggested by Barrell, may have been prevalent, though due only indirectly to atmospheric influence.

Topographic changes would seem to be the preferable explanation for conditions in the Central area. The subsidence, converting that area into vast tidal flats, continued until, just prior to the Ames limestone, the region subject to river and tidal overflow may have embraced more than 20,000 square miles. It must be remembered that in the vertical space occupied by the great reds of the Conemaugh one finds the Cambridge and Ames limestones, both marine. The rivers during long periods of little change had ac-

quired low gradients and they carried little coarse material, which was dropped on the border of the low area, while the streams, flowing sluggishly across the flats distributed the abundant fine materials and, as they shifted their courses, sorted the stuff, giving the lenses of clay and sand. The source of the red material is to be sought at the west, for the reds are present mostly on the west side of the bituminous region—even the great Pittsburgh reds extend only a little way east from the middle line of that region. During contraction of the area of deposition, the Mississippian beds became exposed to erosion while the calcareous deposits of the low-lying Cincinnati had been converted by solution in their exposed portions into red clays such as one sees in so much of the Great Valley within Virginia and Pennsylvania. During deposition of the Pittsburgh reds, residual soils of the northern land must have been an additional source of supply. It seems wholly preferable to regard the Pennsylvania reds as derived from reworking of deposits already red. At the same time, one cannot suppose that the local and widely separated patches in the Monongahela, Washington and Greene were derived from a distant source. Probably they mark the sites of ponds into which the sluggish streams carried muds due to decay of limestones and mingled with those from the fine shale of the red region.

Surface Markings on Shales.—There are no recorded observations of surface markings on Pennsylvanian red shales within the Appalachian basin, though such markings are sufficiently abundant in the Acadian region. But sun cracks and ripple marks are common enough on shale beds of other types. Footprints were found by Mason⁶⁹ on slabs of slate from the roof of the Mammoth coal bed. The surfaces show occasional ripple marks along with the tracks of a four-footed animal arranged in regular sequence. This appears to be the only case recorded within the Appalachian. There is little reason to expect such discovery in the bituminous

⁶⁹ W. D. H. Mason, "On the Batrachian Foot-tracks from the Ellanogowan Shaft in Schuylkill Co., Penn.," *Proc. Amer. Phil. Soc.*, Vol. 17, 1878, pp. 716-719.

region, where one has only natural exposures for study and the shales are so easily disintegrated that only the basset is exposed. Woodworth⁷⁰ studying the more or less indurated shales of the Massachusetts region was led by discovery of rain prints to look for batrachian footprints. The search was rewarded almost at once by discovery of impressions belonging to two individuals. Study of the prints convinced him that they were made under slight cover of water. Many scratches were found on the shale surface, resembling those made by the sharp toes of newts in very shallow water.

In situ forests occur frequently in shale beds. Gresley⁷¹ reported that 7 erect trees were found in the roof of the Buck Mountain coal bed at Haven River colliery. He says that tree-stumps with *Stigmaria* roots are of common occurrence in the roofs of several anthracite beds. That of the Baltimore at Wilkesbarre yielded one, 36 inches in diameter at a few feet above the roots. Comparatively few instances of trees *in situ* have been recorded in the coal fields of the United States and most of the notes, which the writer has found, seem to have been made incidentally and are without detail, as are most of those with reference to similar occurrences in sandstones.⁷² Long ago Owen⁷³ described a forest discovered at 12 miles from New Harmony, Indiana. More than 20 fossil stumps had been found in excavating the site for a mill and dam. He disinterred three with 5 to 7 main roots, which ramified in the surrounding material. As these trees, trunks and roots were in normal position, he believed that they had grown there and had

⁷⁰ J. B. Woodworth, "Vertebrate Footprints on Carboniferous Shales of Plainville, Massachusetts," *Bull. Geol. Soc. Amer.*, Vol. 11, 1900, pp. 449-454.

⁷¹ W. S. Gresley, "Seven fossil Tree Trunks, probably *in situ*, found in Roof of a 12-feet seam of Anthracite in Schuylkill Co., Penn.," *Trans. Manch. Geol. Soc.*, Vol. XXI., 1890, p. 70.

⁷² There is ample reason to expect that when D. White publishes the results of his investigations, all grounds for this complaint will disappear.

⁷³ D. D. Owen, "On Fossil Palm Trees," *Amer. Journ. Sci.*, Vol. XLV., 1843, pp. 336, 337.

become submerged quietly. Lyell⁷⁴ visited this locality at a later date when a quarry had been opened in the overlying sandstone. He saw the trees in a clay shale underlying sandstone and 18 feet above a coal bed. He, with Owen, dug the clay from about one of the trees, which was 4 feet 8 inches high and with roots spreading out as in the normal position. This and two other *Sigillaria*, close by, were casts, the bark converted into coal but the interior filled with mud. The roots were interlaced. A great number of such trees had been removed in working the quarry. Udden⁷⁵ notes that a vertical stump resting on a coal bed was seen by him near Peoria, Illinois, but he gives no details aside from the statement that the stump is filled with sandy clay.

There is, however, no lack of information respecting other lands. Dawson and R. Brown have recorded many instances in the Acadian region; in one case there are *Sigillaria* stumps with *Stigmara* rootlets descending among them from an overlying bed. Occasionally an embryo coal bed existed in the old soil but in some cases there is no trace of coal. The absence of vegetable matter around the base of the stems is in no sense evidence that they are not in place, for Tuomey, as cited on an earlier page, has shown that peat beds raised above the level of water-supply, waste away by drying, the removal being aided by the winds, which carry off the dust-like material. The trees remain, rooted in the underlying soil. Many other students of peat deposits have made the same observation in later years. Gruner says that the lower forest of Treuil has the roots spread out in the roof of the coal and that it is present except where the roof has been washed away and replaced with sandstone. Hawkshaw⁷⁶ described the trees found at Dixon Fold near Manchester. Five of them, at nearly right angles to the stratification, were embedded in a soft blue clay, and a thin coal bed on same

⁷⁴ C. Lyell, "A Second Visit to the United States of North America," 2d ed., 1850, Vol. II., pp. 272, 273.

⁷⁵ J. A. Udden, "Geology and Mineral Resources of the Peoria Quadrangle," U. S. Geol. Surv., Bull. No. 506, 1912, p. 37.

⁷⁶ J. Hawkshaw, "Descriptions of the Fossil Trees found in the Excavations for the Manchester and Bolton Railway," *Trans. Geol. Soc.*, II., Vol. VI., 1842, pp. 173-175.

plane as the roots continues as far as the excavation extends. *Lepidostrobus variabilis* occurs abundantly about the level of the roots, more than a bushel of specimens having been obtained around the trees. A coating of coal, one fourth to three fourths of an inch thick, surrounded the trees, so tender that it flaked off and left the stems decorticated; but some harder coal near the roots of one tree showed the bark fluted longitudinally. The largest tree was 11 feet high, 15 feet in circumference at the base and 7 feet and a half at the top. The next in size was 6 feet high, seven and a half feet in circumference and less tapering; the others were shorter. The roots could be followed only a short distance owing to the character of the excavation. They are covered with a thin stratum of coal, 8 to 10 inches thick, which Hawkshaw thinks probably represents the vegetable covering of the place on which the trees stood.

Binney⁷⁷ says that when erect trees were first found, an attempt was made to refer them to accidents as snags; but discoveries by Hawkshaw and Bowman, near Manchester, aided toward recognition of their growth *in situ*. During a recent examination of excavations for the Bury and Liverpool railway near Wigan, he had discovered not merely a forest of erect *Sigillaria*, with roots just as they had grown, but also many *Calamites* in similar state of preservation. The excavation is about 25 feet deep and in a light gray, silty clay very like that at St. Helens and Dukinfield, where the earlier discoveries were made, and the deposit is between two coal beds. In a distance of 50 yards, he found 30 upright trees and some prostrate stems of *Sigillaria*. They were 2 to 3 feet in diameter, 2 to 12 feet high and filled with silty clay, the bark having been converted into brilliant coal, one fourth of an inch thick. Many *Calamites* were seen among the trees, 4 to 5 feet high, one to 5 inches in diameter, with a thin coaly crust and filled with the silty clay. Each type occurred in all parts of the deposit from top of the lower seam to bottom of the upper. During a second

⁷⁷E. W. Binney. "On Fossil *Calamites* found standing in an erect Position in the Carboniferous Strata near Wigan, Lancashire," *Lond., Edinb. and Dubl. Phil. Mag.*, Vol. XXXI., 1847, pp. 259-266.

visit with Hooker, he discovered *Calamites* with rootlets from joints along the stem. These he describes in detail.

Sorby⁷⁸ relates that 8 large well preserved stumps had been found at Wadsley, rooted in a clay-like shale; all of them *Sigillaria* with *Stigmara* roots. The tops are flat as though sawed off. The largest stump is 5 feet 2 inches in diameter and a huge trunk is prostrate alongside. In all, 10 stems were seen in a space of 40 or 50 yards and all are cut off at the overlying sandstone, with which they are filled. Sorby was much interested by the discovery that the roots are arranged as are those of trees in Great Britain of to-day—they are almost horizontal on the west side but pressed down on the east, showing that the prevailing winds were the same as now. Platt⁷⁹ described a tree rooted in an inferior fireclay with the roots so arranged as to confirm Sorby's conclusions respecting the direction of the winds. W. B. Dawkins, in commenting upon the paper, stated that he had made examination of the tree and that his conclusion was the same with that of Sorby and Platt.

Adamson⁸⁰ described a gigantic *Sigillaria* with 8 forked *Stigmara* roots attached. The area embraced in the ramification of the roots is 826 square feet; it is difficult to conceive of removing this mass by a landslide or on a level area so as to set it down with the stem vertical and the roots outspread in normal position; and the difficulty is increased by the presence of other trees near by. This tree was figured in 1887 by Williamson⁸¹ who says that a larger example was found near that described by Adamson, and that one of the root divisions was traced 37 feet 4 inches to a sharp tip.

⁷⁸ H. C. Sorby, "On the Remains of a Fossil Forest in the Coal Measures of Wadsley, near Sheffield," *Quart. Journ. Geol. Soc.*, Vol. XXXI., 1875, pp. 458-460.

⁷⁹ S. S. Platt, "Notes on a large Fossil Tree recently found in Shales of the Coal Measures at Sparth Bottoms, Rochdale," *Trans. Manch. Geol. Soc.*, Vol. XXIII., 1895, pp. 65-69.

⁸⁰ S. B. Adamson, *Rep. Brit. Assoc. Adv. Sci.* for 1886, p. 628.

⁸¹ W. C. Williamson, "A Monograph on the Morphology and Histology of *Stigmara ficoides*," *Palæontograph. Soc.*, vol. for 1886, pp. 45, 46, 48, 51, Pl. XV.

He states that 7 smaller but similar examples were found in excavations for a street in Bradford.

Grand'Eury and Goeppert have described many occurrences of *in situ* trees; and the former, in his memoir before the Geological Congress at Paris, gave figures and descriptions of *Calamites* with roots from the joints similar to those found by Sorby. Barrois⁸² has reviewed the conditions in a keenly analytical memoir, referring especially to conditions in the Nord basin. His discussion will find place in another connection; it suffices here to note that he has found erect trees only in deposits which have been laid down in shallow water; they are wholly absent from deposits laid down in water deep enough to float the trees.

Not a few writers insist that occurrences of this sort can be explained readily by supposing them to be due to landslides or deluge-like floods. It might suffice to say with Goeppert that the explanation might answer if the instances were few, but that it does not answer because the number of erect trees is so great. But the proposed explanation is wholly unacceptable because the conditions observed do not suggest either landslides or terrific floods.

The White Mountains of New Hampshire have long been celebrated for the extent of landslides. One is typical of all. Perkins⁸³ described that which took place in the southern part of those mountains after a prolonged heavy rain in October, 1869. The light-colored streak marking its path was visible at a distance of 50 miles. The whole mountain had been covered with a dense growth of spruce. The slide began at 40 rods below the summit, 4,200 feet above tide. It was barely one rod wide at the top and increased little in the first 50 rods, where the slope is between 50 and 60 degrees; but, in the next 100 rods, the width increased rapidly to 25 and 30 rods at 130 rods from the beginning; thence it decreased to 17 at 166 rods. The whole length is nearly 240 rods and the outline is fusiform. Three miles below the termination of the

⁸² C. Barrois, "La répartition des arbres debout dans le terrain houiller de Lens et de Lievan," *Ann. Soc. Geol. du Nord.*, Vol. XL., pp. 187-196.

⁸³ G. H. Perkins, "Notice of a Recent Landslide on Mount Passaconaway," *Amer. Journ. Sci.*, II., Vol. XLIX., 1870, pp. 158-161.

slide, a level clearing through which Mad River flows, was covered with great heaps of logs brought down by the slide and swept away by the freshet attending it. They were broken and shattered, though some were 60 feet long. They were piled up confusedly to a height of 15 or 20 feet, stripped of foliage and most of the smaller branches. Farther up the stream, no trees were visible; they had been buried in the coarse debris of the slide.

The terrific discharge of Lake Mauvoisin has been cited as evidence that blocks of the surface could be transported with standing trees and be deposited in the normal position. Knowledge respecting this great débâcle is derived from the description by Escher von Linth, of which a synopsis was published in English.⁸⁴ The Val de Bagnes is drained by the river Dranse, whose progress had been impeded for several years prior to 1818 by blocks of ice and by snow avalanches from the glacier of Getroz. At length the river was dammed and a lake was formed, which became 10,000 to 12,000 feet long, 700 feet wide at top, 100 feet wide at bottom, with an average depth of 200 feet. The content equalled at least 800,000,000 cubic feet. A gallery, 600 feet long, was cut to drain the lake, but this enlarged quickly in the ice, so that before one half of the water had passed off, the dam gave way and the mass of ice, water and débris was precipitated into the valley below. The whole lake was emptied in less than half an hour and the author well says that one cannot describe the violence of the flood. The passage of the water was checked by a narrow gorge, where it tore away a bridge, 90 feet above the preëxisting stream; beyond that, it entered a wider part of the valley, only to be banked by another gorge beyond. Thus passing from one basin to another, it acquired new violence and carried along forests, rocks, houses, barns and the cultivated surface. The flood seemed to contain more débris than water and it moved at the rate of 18 feet per second. The acquisition of these materials made the current more effective and, when it entered the narrow valley leading from Saint Branchier to Martigny, it con-

⁸⁴ "Account of the Formation of Lake Mauvoisin by the Descent of a Glacier and of the Inundations of the Val de Bagnes in 1595 and 1818," *Edin. Phil. Journ.*, Vol. I., 1819, pp. 187-191.

tinued its work of destruction until weakened by spreading over the great plain of the Rhone valley. After ravaging Le Bourg and the village of Martigny, it fell with comparative tranquillity into the Rhone, "leaving behind it on the plain of Martigny the wreck of houses and furniture, thousands of trees torn up by the roots and the bodies of men and animals, which it had swept away."

Neither landslide nor vast flood can be invoked for explanation of phenomena such as those described by Adamson, Potonié and Binney. It is incredible that the work of such destructive agents would leave no record except a group of trees resting normally with the roots of one interlaced with the roots of the others. There is no trace of disturbance at any locality mentioned by the observers named or by any others; yet the discoveries by Binney, Hawkshaw, Bowman and Platt are in the same small area, each covers a considerable space and everywhere there is evidence of wholly undisturbed deposition. The evidence that the trees are *in situ* is as strong as it is for Russell's gravel buried forest in Alaska or for the sea-covered forests on the shores of the Baltic and Britain.

The trees *in situ*, the ripple marks, rain and footprints, the evidence of selective action by streams, all go to show that shales were deposited in, at most, shallow water and that great areas of the Appalachian basin, like other regions in which shales occur, were above the area of deposition for prolonged periods.

The Limestones and the Marine Deposits.—Four limestones, with marine fauna, have been discovered in the Warrior coal field of Alabama, all, except possibly the highest, in the New River; Safford discovered a "local bed" of hard crinoidal limestone in his Upper Conglomerate within Grundy county of Tennessee, also New River; M. R. Campbell found a marine fauna in southern West Virginia within the New River and D. White⁸⁵ obtained *Spirorbis* and *Naiadites* in the southern anthracite field. The last is possibly brackish water; the others, distinctly marine, show that during the New River salt water occasionally had access, at least locally,

⁸⁵ D. White, "Deposition of the Appalachian Pottsville," *Bull. Geol. Soc. Amer.*, Vol. 15, 1904, p. 277.

as far north as New River of West Virginia on the eastern side of the bituminous region.

Evidence of marine conditions here and there in the northern half of the basin becomes distinct early in the Beaver. On the southeast outcrop along New River, West Virginia, one finds a silicious limestone, non-fossiliferous, of which traces appear at localities farther west almost to the Kentucky line. Somewhat higher is the Eagle limestone of I. C. White, black, blocky and, as are also the associated shales, richly fossiliferous. These deposits seem to be unrepresented farther north and to be confined to a narrow area in West Virginia. No trace of limestone or of any marine deposit within the Beaver is known east from the Allegheny mountains; none has been observed within the first three bituminous basins of Maryland, Pennsylvania or West Virginia, unless the Black Flint of the last state belong to the Beaver and not to the Allegheny,—and it is confined to a small area near the Kanawha River; nor is there any along the northern outcrop in Pennsylvania and Ohio. In northern Mercer county of Pennsylvania, 60 miles south from Lake Erie, one is on the northern limit of the Upper and Lower Mercer limestones of I. C. White, which are in the shale mass underlying the Homewood sandstone and are associated frequently with iron ore.

These deposits are persistent southward along the Ohio-Pennsylvania boundary for about 40 miles but they rarely extend eastward from that line to more than 25 miles. The limits of their area are well marked, north, east and south, within Pennsylvania and no trace is found beyond. The upper limestone is of irregular occurrence in Ohio but the lower bed is persistent with, in several counties, its boundaries at east and west thoroughly well defined. It crosses Mahoning, Portage and Summit, but it is wanting in Medina at the west. It is wanting in the panhandle counties of West Virginia and in eastern Ohio to about 40 miles west from the Ohio River. The Lower Mercer is present southward from Portage and Summit in an irregular strip, 30 to 50 miles wide, to Vinton county and it enters the northwest corner of Scioto at about 20 miles north from the Ohio River. The western boundary is reached

at several localities in the northern part of the state, but, for the most part, the present outcrop is east from it as the limestone area seems to follow irregularly the direction of the pre-Beaver valley in which the Sharon sandstone, or latest deposit of the New River, was laid down. For this reason the limestone is found nowhere in Kentucky. The thickness at the north rarely exceeds 5 feet, but it increases southwardly to 10 feet. The Upper Mercer is less persistent than the Lower, but its unexpected appearance at some localities suggests that its area lay farther west. Both limestones are richly fossiliferous, each being at times a mass of shells. They indicate ingress of the sea in a narrow area, probably nowhere exceeding 50 miles in width and reaching northward to within 60 miles of Lake Erie along the Pennsylvania-Ohio line.⁸⁶

The sea again invaded the basin soon after the beginning of the Allegheny, for the Putnam Hill limestone of E. B. Andrews rests on the first coal bed of that formation. It did not reach into Pennsylvania but it is followed easily in Ohio from Mahoning county near the Pennsylvania line to Perry county, where its character so changes that the bed is no longer available as a stratigraphic guide. In much of its extent, this limestone is associated with flint and iron ore and it shows great variation in thickness as well as in composition. Beyond Perry county, its area of deposit lay west from the outcrop and only the iron ore remains to mark its horizon. It carries an abundant marine fauna at most localities. At not far from the Putnam Hill horizon one finds the Kanawha Black Flint which occupies a small area on both sides of the Kanawha River in West Virginia toward the southeastern outcrop. The probabilities are, according to the plant remains, that it belongs lower in the column. This black calcareous rock is embedded in black shale and the mass is rich in marine forms. The area is more than 100 miles east from the eastern limit of the Putnam Hill and Mercer limestones, so that, like the Eagle limestone, it is evidence that the sea had ingress on the eastern side of the bituminous region.

⁸⁶ The observations by I. C. White, Newberry, Andrews, M. C. Read, Stevenson, Orton and A. A. Wright are recorded in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 15, pp. 66-70, 80-86, 89-91.

Not long after deposition of the Putnam Hill, but long enough for deposition of 40 to 80 feet of inorganic materials, the formation of two coal beds and the erosion of broad valleys, another sea invasion is recorded in the Vanport limestone of I. C. White. This underlies in most of its extent an ore deposit, which in the earlier days was so important that the rock below was termed the Ferriferous limestone. Like its predecessors, it is confined to the west side of the basin. A fossiliferous limestone is present in the Lower Allegheny at some places in western Maryland, but one cannot determine whether or not it is contemporaneous with the Vanport, as no fossiliferous limestone has been found at the horizon within 80 miles toward the west or northwest. The Vanport appears to be wanting in the whole of West Virginia as well as in Pennsylvania south from the line of the Ohio River. The deposit is recognized first at about 70 miles north from the West Virginia line and at an equal distance west from the crest of the Allegheny Mountains.

The most easterly locality in Pennsylvania, from which this limestone has been reported, is in Indiana county at 75 miles east from the Ohio line—apparently the tip of a prong; it appears at many places in the next county north, but its distribution indicates that the area is broken into prongs; and this is the mode of occurrence along the northern border where its limits are very well defined. From western Jefferson, the area is continuous to the Ohio line where the bed is 15 to 20 feet thick. The deposit is less regular in Ohio, being represented in many places by fossiliferous shale, calcareous sandstone and occasionally by limestone. These conditions prevail in Mahoning, Columbiana, Stark and western Tuscarawas, the limestone being of frequent occurrence in the last. Thence southward into Elliott county, Kentucky, the limestone with its ore seems to be continuous; beyond that the ore bed is traceable for many miles. The western boundary of the deposit is reached at a few localities in northern Ohio but, for the most part, it is beyond the present outcrop. While the extent of the Vanport in Ohio may have been less than that of the Mercer, its extent in Pennsylvania was far greater. The sea-invasion reached 60 miles farther east into Indiana county and 70 miles farther north into

McKean county on the New York border. The area in Pennsylvania was not less than 3,000 square miles, while that of the Mercer was little more than 500. At the same time, one must keep in mind that the Vanport was not continuous throughout its area; that on the borders it extends in long diverging prongs, terminating in chert or calcareous sandstone. The Vanport was formed at the close of a somewhat rapid submergence, during which many stream valleys were filled with sandstone. Apparently the peculiar mode of occurrence, the variations in structure and composition along the borders were due to the topography; while the conditions in northern Ohio suggest that in that region the water of the estuary was very shallow. In Pennsylvania and in a great part of the Ohio area, this limestone has a rich marine fauna.⁸⁷

The roof shale of the Middle Kittanning coal bed, midway in the Allegheny, contains *Lingula* and *Discina* as far north as Wayne and Stark counties of Ohio. Aside from this, there appears to have been no serious invasion during the Allegheny after the Vanport. There are, it is true, several limestones, but there is no reason to suppose that, excepting the newest of them, they are in any part of marine origin. The Upper Freeport, almost the last Allegheny bed, is the First Fossiliferous limestone of Kentucky, where it has a marine fauna, but, north from the Ohio River, it resembles the others in that the only fossils are minute forms, allied to those usually regarded as freshwater types.

The Uffington shale of I. C. White, the roof of the Upper Freeport coal bed, often yields abundance of plant remains, but at some widely separated localities on the eastern side, in Monongalia and Upshur counties of West Virginia, as well as in Wirt county of the same state, far within the Central area, it has a marine fauna accompanied by fragmentary remains of plants. Whether or not the fauna exists elsewhere in the Central area is unknown, as the horizon is below the surface and the well records are of no service. The distribution of this deposit is without explanation in the present

⁸⁷ The observations by I. C. White, W. G. Platt, Chance, Newberry, Orton, Hodge and E. B. Andrews are recorded in "Carboniferous," etc., as above, Vol. 17, 1906, pp. 98-103, 113, 109-113, 116-121, 128.

state of knowledge. Where plant-bearing, this shale resembles the ordinary roof shale, but where carrying remains of animals it is black, somewhat sandy and occasionally somewhat fetid. It recalls conditions described by A. Agassiz as existing in the Pacific ocean between Mexico and the Galapagos islands.

The Uffington shale was followed by the often coarse and massive Mahoning sandstone, containing one or more coal beds of considerable extent, and that in turn was succeeded by a coal bed underlying the Brush Creek limestone of I. C. White, the Black Fossiliferous limestone of the early Pennsylvania reports. This dark, almost black rock, enclosed in black shales, is the first limestone which crossed the bituminous region and reached the line of the Allegheny Mountains—it is recognized without doubt in western Maryland. The deposit is wanting along practically the whole eastern outcrop in West Virginia and most probably throughout the interior of that state, for it has not been found under the great anticline in Wirt county and black shale, at this horizon, is not recorded by the drillers of oil wells. It is persistent in western Pennsylvania, which it enters from Preston county of Virginia and Garrett of Maryland. The area, narrow at first, widens to 15 or 20 miles farther north and retains that width to the Ohio line. Thence it is present for 40 or 50 miles southwestward into Jefferson county of Ohio, beyond which it seems to be wanting for about 30 miles. But it reappears and is followed easily into Muskingum county, beyond which no trace exists, the horizon being exposed at very many places. The gap beyond Jefferson county is evidently due to erosion, but there is no reason to suppose that the limestone ever existed south from Muskingum county. The limestone and shales are crowded with a marine fauna and the conditions indicate that it was deposited in an estuary opening at the east.**

The Cambridge limestone of E. B. Andrews is at a little distance higher in the Conemaugh column. A marine limestone, very near this horizon, is in western Maryland, but that locality is more than 75 miles east from the nearest outcrop of the Cambridge; its rela-

** For the observations by Martin, I. C. White, Newberry, Stevenson, and Orton, see "Carboniferous," etc., as above, pp. 167-189.

tions are with the eastern side. The most easterly point in Pennsylvania, at which the Cambridge can be recognized with certainty, is almost 60 miles east from the Ohio line and about 70 miles north from that of West Virginia. Thence it is persistent into Ohio. The direction of the area is almost westward in Pennsylvania but in Ohio it becomes west of south, and the bed is easily followed across that state and Kentucky to the last exposure of its horizon. In southern Ohio and in Kentucky it extends eastward beyond any predecessor and at the south it reaches into West Virginia; but it is absent under the Wirt anticline in both Ohio and West Virginia. In Pennsylvania, its area is far less than that of the Vanport and the thickness rarely attains 8 feet. The distribution of the deposit indicates a return to the earlier condition, as this is confined to the west side. The abundant fauna is marine.⁸⁹

Midway in the Conemaugh is the remarkable deposit, the Ames limestone of E. B. Andrews, the Green Fossiliferous limestone of the early Pennsylvania reports. It overlies the Pittsburgh reds, from which it is separated in extensive areas by the Harlem coal bed and the associated shales. It has not been discovered anywhere east from the Allegheny Mountains unless one accept as its equivalent the Mill Creek limestone of the Northern Anthracite field, which certainly is in the Conemaugh, possibly not far from the Ames horizon. The Ames is thin, seldom more than 4 feet, and is more or less argillaceous, especially on the eastern side. The color is bluish green, thoroughly characteristic in most of the area, so that the bed is a most important stratigraphic guide. Along the eastern border it has been recognized positively to 75 miles south from the Pennsylvania line; it is present in western Maryland and southwestern Pennsylvania, wherever its horizon is exposed; it is equally persistent in Ohio and Kentucky, being the Fourth Fossiliferous limestone in the latter state. It extends on the west side to the middle line of the basin, being exposed under the Wirt anticline in both Ohio and West Virginia. It was deposited in an area

⁸⁹ For observations by Martin, I. C. White, W. G. Platt, Stevenson, Orton, Andrews, Lovejoy and Bownocker, see "Carboniferous," etc., as above, pp. 168, 175-180, 183-194, 197-201.

of not less than 16,000 miles, possibly much more, since no information can be derived from the ordinary well records. This widely extended deposit was certainly not continuous with the Mill Creek limestone of the Northern field; the nearest outcrops of the two rocks are separated by 150 miles, including a part of the bituminous region in which the Ames never existed. The fauna is marine throughout, even on the extreme western border in Meigs county of Ohio where Condit⁹⁰ found the limestone impure, sandy, ferruginous, conglomeratic with pebbles of sandstone and with sun cracks on its upper surface. This marine invasion, affecting the greater part of the Conemaugh area, followed the deposition of the fine muds known as the Pittsburgh reds and was succeeded by the Washington reds. Even where the reds are absent, the limestone is usually between deposits of fine grain. Marine conditions preceded it and continued after it; shales equivalent to the Pittsburgh reds carry a marine fauna at some localities and, in Pennsylvania, marine forms persisted up to 50 feet above the limestone.⁹¹

The only limestones in the anthracite region are in the northern field, where they were seen by Ashburner. Three of them are without fossils but the fourth, the Mill Creek at 688 feet above the Baltimore coal bed and one foot thick, has a marine fauna. A black shale at Dundee, in the same field and 250 feet above the limestone, has the same assemblage of fossils. A peculiar feature of this fauna is that it includes some forms unknown elsewhere in the Appalachian basin, though abundant in the coal area beyond Cincinnati—which seems to indicate communication by some other way than that at the southwest.

Marine invasions practically ceased with the Ames episode: there are other beds of limestone in the upper part of the Conemaugh but they appear to be at least non-marine.

Five limestones have been recognized in the Monongahela, but they are confined to a small space in southwestern Pennsylvania and

⁹⁰ D. D. Condit, letter of April 24, 1912. The locality is Sec. 10, Salem township, Meigs county.

⁹¹ The observations by I. C. White, Stevenson, W. G. Platt, Martin, Newberry, Hodge and Andrews are recorded in "Carboniferous," etc., as above, pp. 167-202, 208, 211, 215.

immediately adjacent parts of Ohio and West Virginia, in all less than one fifth of the present area of the formation. The deposits are especially important in Pennsylvania between the Monongahela and Ohio Rivers, perhaps 2,000 square miles, but they disappear rapidly in all directions. The extreme development is near Wheeling on the Ohio, where one finds 154 feet of limestone in 190 feet of measures; but nearly the same thickness is shown near the Monongahela, where, however, the section is longer, as it has sandstones and shales which are wanting at Wheeling. These deposits vary from almost pure limestone to calcareous shale, and in much of the area they are in layers one to 4 feet thick, separated by much thinner layers of calcareous shale. Their appearance is so characteristic that one familiar with them in any locality could hardly mistake Monongahela limestones elsewhere for those of any earlier formation. Animal remains are confined to a few types. Minute forms, resembling the ostracoids found in the upper limestones of the Conemaugh, are abundant at many places. Teeth of *Helodus* and a spine of *Ctenacanthus marshii* have been collected from midway in the formation within Washington county of Pennsylvania; the fourth limestone is rich in *Naiadites* near Uniontown, Pennsylvania, and a blue shale near Morgantown, West Virginia, contains abundance of *Solenomya*. The fish remains are the same with those which abound in the marine limestones of Illinois, but these marine forms are evidence of sea invasions so brief as to have no significance, for they are unaccompanied by marine molluscs. All the features indicate that the Monongahela limestones are, in greatest part, of freshwater origin.

The Washington formation has six limestones, confined practically to Greene and Washington counties of Pennsylvania, all, except one, disappearing quickly in each direction. They resemble those of the Monongahela, some being covered with similar forms, thought to be of freshwater types. Larger fossils are very rare. I. C. White obtained from a black shale in the upper portion scales of *Rhizodus* and other fishes, which are most probably freshwater in their relations, as the same genera occur in a cannel layer at Linton, Ohio. The Greene formation has many limestones within

southwestern Pennsylvania, but apparently most of them are mere lenses and few of them can be regarded as definite members of the section, though they are the striking feature in the lower half of the formation. The Nineveh limestone, however, is persistent, having been recognized along a line of more than 100 miles, and is 22 feet thick at its last outcrop in West Virginia—strangely persistent in an area where every other bed in the column is changeable. Although the beds have small extent, the quantity of limestone in the Greene is very great. Fossils are rare; minute forms, mostly ostracoids, occur in many beds and occasionally one finds in the shales a form resembling *Naiadites*. Some of the more argillaceous limestones contain much finely comminuted vegetable matter.

The composition and structure as well as the fossils in many limestones above the Ames horizon have led to the belief that they were deposited in freshwater basins; and evidence of like character is not wanting in some of the Allegheny limestones.

I. C. White⁹² found that the Upper and Lower Freeport limestones are very often brecciated in some of the layers and concluded that they had been deposited as muds in inland lakes—conclusion very like that of E. B. Andrews presented in 1873. Ostracoids are abundant in the Upper Freeport. Farther south in Pennsylvania, the brecciated limestones appear toward the end of the Conemaugh and the fossils are ostracoids along with forms resembling *Spirorbis*. The limestones of the Monongahela, Washington and Greene are brecciated at very many localities and some of them rarely show normal structure. Ostracoids and *Spirorbis*-like forms are extremely abundant in some.⁹³ Hyde's⁹⁴ observations in Ohio prove that conditions are the same in that state. A limestone in Noble county, below the Ames, about 10 feet thick, has an irregular top owing to erosion prior to deposition of the overlying sandstone. The upper surface is mud-cracked and the cracks are filled with

⁹² I. C. White, Sec. Geol. Surv. Penn., Rep. Q, 1878, contains numerous illustrations; Rep. Q2, 1879, p. 220.

⁹³ J. J. Stevenson, Sec. Geol. Surv. Penn., Rep. K, many references.

⁹⁴ J. E. Hyde, "Desiccation Conglomerates," *Amer. Journ. Sci.*, IV., Vol. XXV., 1908, pp. 400-408; letter of January 12, 1912.

shale. Some layers are crowded with tubes resembling those of annelids. The overlying sandstone contains limestone fragments in the lower portion. A conglomerate limestone in Belmont county, and very near the top of the Conemaugh, shows shrinkage in the limestone fragments. The Monongahela limestones in the same county vary from hard to soft, often becoming calcareous shale. Shrinkage cracks are so numerous at times as to give a brecciated structure. These limestones contain several species of minute ostracoids which are very abundant, and in some beds one species of ostracoid is well represented. These cover the bedding planes and are shown especially well on sun-cracked surfaces. Conglomerate layers are frequent, varying in thickness from half an inch to 3 or 4 inches, and the fragments are from pea-size to several inches in diameter. Hyde thinks the deposits are of freshwater origin like the freshwater limestones in some of the western states and he conceives that they represent the calcareous mud laid down in probably shallow bodies of water. During the summer, the water was evaporated and the ostracoids with the *Spirorbes* were left on the muddy surface, which, exposed to the heat, became sun-cracked. A similar explanation was suggested by Haast⁹⁵ who, in describing some Tertiary marls, says that they must have been "left high and dry, exposed to the effects of a powerful sun, is well shown by numerous cracks in the clay marls, which are several inches wide and deep."

Brecciated limestones have been reported frequently from other lands and the explanations offered are not wholly concordant. Roeder⁹⁶ found in the Lancashire field a succession of red shales and clays with thin coals and two limestones, in all somewhat less than 900 feet thick. At Slade lane he saw 206 feet of measures, mostly red, green or variegated shales with in all 21 feet 4 inches of limestone. Some of the limestones are brecciated locally and the passage from breccia to the normal structure is gradual. The frag-

⁹⁵ J. Haast, "Report on Geology of the Malvern Hills, Canterbury," Rep. Geol. Surv. N. Z., 1872, pp. 63, 64.

⁹⁶ C. Roeder, "Notes on the Upper Coal Measures at Slade Lane, Burnage," *Trans. Manch. Geol. Soc.*, Vol. XXI., 1890, separate, pp. 7-22.

ments are from pinhead to 2 inches and the larger ones are angular, the edges at times jagged; the smaller pieces are more rounded. In weathering, the fragments give way first, which leads Roeder to suppose that they must have suffered from subaerial exposure before entombment. He regards the condition as proof of occasional elevation and exposure, when older limestones were broken up and either transported or left *in situ*. Additional evidence in favor of this conclusion was found in his discovery of angular fragments of the *Spirorbis* limestone in sandstone at Ardwich. He cites Hull and Williamson to show the wide occurrence of brecciated limestone in England.

De Dorlodot⁹⁷ discussed the great breccia in the upper part of the Carboniferous within the Franco-Belgian basin. He says that some geologists have supposed it to be due to dynamic action, but he believes it sedimentary, due to destructive attack by waves and the rapid accumulation of the products. The elements vary much in size and the paste, filling spaces between large and small blocks, is itself partly limestone. The fragments, large and small, have their angles but slightly rounded. In any event, they could not have come from far.

Stainier⁹⁸ took vigorous exception to de Dorlodot's explanation, because nothing of the sort is known in actual times. The supposed conditions exist at many places along the coast of Great Britain, but no breccia forms. If, by change in conditions, the shallow Carboniferous sea should be dried up completely, the exposed limestone would be a desert surface. The contrast in temperature would break up the rock and give material for the breccia. When the sea returned and invaded the area, it would sort the materials. The coarse blocks would be moved little, the less coarse, farther; by insensible gradation one passes to the compact limestone which, east from Namur, occupies the breccia horizon.

It is difficult to believe that the brecciation was caused by ex-

⁹⁷ H. de Dorlodot, "Sur l'origine de la grande brèche Viséenne," *Bull. Soc. Belge de Geol.*, Vol. XXII., 1908, Mem., pp. 29-38.

⁹⁸ X. Stainier, "Du mode de formation de la grande brèche du Carbonifère," *Bull. Soc. Belge de Geol.*, Vol. XXIV., 1910, P. V., pp. 188-196.

posure after the limestone had become consolidated; the features in most cases are those observed where a moist material, still soft, is exposed to the air; the brecciation is that of cracking due to loss of moisture. Haast's explanation, more or less modified by later students, is evidently the one most closely related to the facts.

Perhaps some reader may hesitate to believe that limestones as thick as those of western Pennsylvania can be of freshwater origin; but they are not greater than some recent marl deposits within the United States. Davis⁹⁹ has discussed the whole subject showing the mode in which the material accumulates and its relation to peat deposits. D. J. Hale, in the same volume, described many Michigan deposits, 20 to 47 feet thick. Blatchley and Ashley¹⁰⁰ have shown that conditions are the same in Indiana as in Michigan. They are convinced that the supply of calcareous matter was ample in later Coal Measures times, for limestones must have cropped out in extensive areas and the springs in much of the region must have been charged with dissolved limestone. But both the Appalachian limestones and the western marls are insignificant when compared with those of the Tertiary lignite area of l'Aude in France.¹⁰¹ The section at Cavenonetti shows at top a freshwater limestone, nearly 80 meters thick. Some of its beds are rich in river shells and others are equally rich in *Lymnæa* and *Planorbis*, which are found also in the shales and in the lignite. A similar limestone, 10 to 15 meters thick, is lower in the section and the lowest member exposed is of the same type.

The presence of *Spirorbis* has been regarded by some as an objection to acceptance of freshwater origin for the limestones, for beyond all doubt that form is related to marine types. It occurs throughout the Coal Measures column, sometimes in deposits which are certainly marine and at other times in deposits which are dis-

⁹⁹ C. A. Davis, "A Contribution to the Natural History of Marl," Geol. Surv. Mich., Vol. VIII., Pt. III., 1903, pp. 65-96.

¹⁰⁰ W. S. Blatchley and G. H. Ashley, "The Lakes of Northern Indiana and their Associated Marl Deposits," Twenty-fifth Ann. Rep. Geol. Surv. Ind., 1901.

¹⁰¹ (M) de Serres, "Observations géologiques sur le Département de l'Aude," Soc. des Sci. Lille, 1835, pp. 453-455.

tinctly not marine. The best summary of the conditions was given by Barrois,¹⁰² who was led by the apparently contradictory modes of occurrence to make thorough investigation of the whole subject. Some of his conclusions will find place in another connection but others are of interest here. He found *Spirorbis* shells attached to living plants, to plant débris, to brackish and even to essentially salt water animals. In the larval condition, the type is free but in the adult, fixed. It is allied to *Vermetus* and *Spirorbis* of the present time, all marine. To reconcile the existence of such forms on plants essentially terrestrial, one must admit that the original Carboniferous *Spirorbis* lived fixed on marine shells; that the descendants became habituated to brackish water, where they attached themselves to *Carbonicola*; and at last to fresh water, where they became fixed on ferns. It is very evident that the conditions noted by Barrois exist in the Appalachian basin, so that the presence of *Spirorbis* cannot be regarded as evidence for or against any hypothesis respecting the character of the water.

It is quite possible that the occurrence of *Naiadites* may be evidence of brackish water invasions.

Reference has been made to very dark carbonaceous or bituminous limestones, of which the Brush Creek may be taken as type. They are not numerous. Their fauna is marine, they are often fetid and, at times, have some vegetable matter. The Brush Creek limestone, as has been shown, occupies a long narrow area, bordered by shales and sandstones and, at some localities in both Pennsylvania and Ohio, it suffered severely from erosion prior to deposition of the overlying rock. De Dorlodot¹⁰³ has discussed the origin of sapropelic limestones and his conclusions seem to require examination at this point. Some crushed polyps, exhibited at a meeting of the Geological Society, were in a gangue which had undergone slow compression, such as that which Potonié had recognized as characterizing sapropelian muds. A. Renier had accepted sapro-

¹⁰² C. Barrois, "Sur les Spirobes du Terrain Houiller de Bruay (Pas-de-Calais)," *Ann. Soc. Geol. du Nord.*, Vol. XXXIII., 1904, pp. 50 et seq.

¹⁰³ H. de Dorlodot, "Sur les conditions de dépôt des marbres noirs dinantiens et des sapropelites marines en général." *Bull. Soc. Belge de Geol.*, Vol. XXV., 1911, P. V., pp. 146 et seq.

pelian origin for the black limestone of Hun and F. Kaisin had done the same for the Dinant marbles. De Dorlodot agrees with Renier that the limestone is marine but dissents from the opinion that it is a coast deposit. The conditions and stratigraphical relations had led him to believe that it was deposited far from shore, for the deposits are not local, they are extensive and their lithological character suggests deep-sea origin.

According to de Dorlodot, Renier's decision in favor of shore deposit depends upon the presence of terrestrial plants and of sapropelic matter in the limestone; but presence of remains of terrestrial plants is irrelevant, for A. Agassiz found them far from shore and in deep water off the Pacific coast as well as in the Gulf of Mexico. Sapropel deposits can be formed along coasts only in lagoons or in bays protected against movement of the waves. Proximity to the coast is not possible, for action of the waves would cause continuous oxygenation of the water. The deep sea would be most favorable to accumulation. He supports his opinion by reference to carbonaceous shales of the Toarcien, asserting that their geographical extent is proof that they were not deposited in isolated bays, while their fauna proves deposit in the maximum of immersion—and those shales contain remains of land plants. The fact that deep sea soundings in our day show no sapropelian deposits is not final. The problem is not to explain why the old marine rocks are so rich in kaustobiolithitic materials, but why modern deep sea deposits are so poor. The problem may be stated in another way. How is aerobian life possible in great depths of the ocean so as to cause destruction of the organic matter which the plankton must afford? This is explained by the bottom-creep of oxygenated water from the poles; in the Black sea, which is beyond the influence of that creep, there are only anaerobic organisms in its depths. Sapropelic character does not prove shore origin—it rather tends to establish and at times to demonstrate deposition at distance from the shore and at great depths. De Dorlodot believes that the limestones under consideration were deposited far from the coast and in calm water.

It is difficult to discover the force of this reasoning and equally

difficult to understand the bearing of some of the arguments upon others. That from geographical extent is unimportant for the Brush creek limestone has been traced 150 miles and it must have had a notable area in the now eroded region at the east. Nor does it seem essential to deposition of sapropel that the water be calm. Potonié has told of extensive lakes in Germany, formerly navigable but now choked with sapropel. The surface of navigable lakes, great or small, is apt to be churned into waves. No reason can be assigned why the Frische Haff, at the mouth of the Vistula, may not be filled with sapropel, provided conditions remain as now. The presence of fragments of land plants is not of itself final evidence of deposit in shallow water or on an offshore area; but the discoveries by A. Agassiz hardly relate themselves to the matter, for he did not report the presence of sapropel material in mud holding fragments of rotten wood, though the region is one as favorable to accumulating such material according to de Dorlodot's conception as one can imagine. The arctic creep must be at its minimum in the Gulf of Mexico. One may hardly refrain from suggesting that de Dorlodot has not conceived the problem fairly. Unquestionably the absence of kaustobiolitic materials from deep sea deposits of this day is as perplexing as interesting and the explanation offered by that author may or may not be correct. But that is not the serious problem, for most of the Coal Measures marine limestones are as free from sapropel as are the present deep-sea limestones, so that conditions then were very much like those of this time. The assumption throughout the discussion is that the marine fauna of the limestone indicates very considerable depth of water, the maximum of immersion. Even this is open to question. True, it is in accord with the prevailing opinion, which, having been unchallenged for a long period, has become, for many, one of the fundamental pillars of geology. Studies by palæontologists in the Appalachian areas lend no support to the belief that deep water covered the Appalachian basin during the Palæozoic and the stratigrapher hails their conclusions with gratification, as they coincide with his own. These conclusions and the arguments supporting them will be found on a later page. The arguments are applicable equally to conditions in other lands.

The use of the term currents to explain local conditions is apt to be misleading. There is no good reason for supposing that there were any currents in the Appalachian basin. The close succession of often coarse sandstones upon marine limestones, even upon sapropelic limestone, shows that the deposits were near a shore.

A review of the conditions leads to conclusions the same as those suggested by deposits of other materials. The marine limestones are local, are in areas which, for the most part, can be determined closely. Those of the earlier formations are found on both sides of the Alleghenia ridge, but the localities, at which observations have been made, are too widely separated to admit of an attempt to determine their relations. The Beaver and Allegheny limestones, however, have been traced in detail. On the western side, within the Ohio basin (of Schuchert), they followed in a general way the direction of the pre-Beaver valley in Ohio but as they approached the Pennsylvania line, they turn eastward into that state. This variation becomes notable in the Vanport, which seems to have followed rather closely in Pennsylvania the lines of valleys eroded during the immediately preceding times. There can be no question that the early drainage line, established prior to Beaver time, persisted until the middle of the Allegheny and that it determined the area of sea-invasion, as the old river valleys along the Atlantic coast have done in recent times. The extent of the limestones, though they follow the same line in great part, shows that the estuaries, due to drowning of the valleys, were not of equal length. When one examines the conditions on the eastern side, he finds that, in the Beaver and Allegheny, the marine limestones occur within a small area in West Virginia. Erosion has removed the Pennsylvanian from a great expanse on the eastern side so that the relations of these limestones cannot be determined beyond the present exposures, but the deposits seem to mark the upper portion of successive estuaries along the same general course. The sea-invasion on this side may not have reached so far north as on the western.

In the early Conemaugh, the conditions were somewhat different.

The long serpentine course of the Brush Creek limestone from Maryland to central Ohio shows that, while there had been no great topographical change and the whole area was still lowland, there had been enough change during deposit of the underlying sandstone to make possible, by slight submergence, a broad, continuous drowned valley across nearly the whole bituminous region,—from very near the eastern outcrop westward to the line of the pre-Beaver valley. This depression did not affect the southwestern part of the region as there is nothing there answering to the Brush Creek; the invasion was from the east. But during the next interval, the earlier conditions were restored and one finds the Cambridge limestone following approximately the course of the Vanport in Pennsylvania, Ohio and Kentucky, though reaching farther eastward in the latter states. But at about the same time, there was a new invasion on the eastern side along the line of Brush Creek estuary, for a marine limestone is present in western Maryland while farther west near the Monongahela River in West Virginia, there is a non-fossiliferous limestone, which may represent the shore phase of the same deposit.

The Cambridge limestone marks the temporary culmination of a long continued subsidence which brought a constantly widening area on the west side to sea-level and eventually below it. That area continued to widen eastward and reached its maximum when the Ames limestone was deposited. Peneplanation of the bituminous region had become far advanced; for a long period only fine material had been brought down by the streams and a very great part of the region had become converted into mud flats through which the streams meandered in shifting channels, sorting the fine clays and sands. The rivers must have emptied into estuaries around the border for marine conditions existed as far north as the southern line of Pennsylvania just prior to the Ames. Limestone deposition began first at the west, the thickness and purity of the rock being best marked in Ohio, and advanced east and northeast until the bed covered a great part of the bituminous region. The efflux of the cleaner water was abrupt, but the limestone is followed by fine deposits at most localities and it was not until 70 feet of shales had been laid down in much of the region that the normal conditions were restored. It is possible that the 70 feet of muds, in which

there is evidence of marine life, may be the measure of the extreme possible depth at which the Ames limestone was deposited. Indeed one is tempted, in view of conditions observed on islands in mid ocean, to suggest that the abrupt appearance of muds above the Ames might be regarded as evidence that the limestone was deposited in very shallow but very clean water; and the temptation is the stronger, because stream-sorting appears in the arrangement of materials composing the overlying shale.

Were these limestones deposited in deep water? The testimony of the fossil remains in answer to this question will be examined on a succeeding page; but there are several matters to be considered here. In some cases, the limestones can be followed to their disappearance. The Vanport limestone in Pennsylvania ends in long prongs within Pennsylvania, gradually passing into sandstone, *débris* from the sides of the valleys in which the limestone terminates. And fossils continue after the change has begun. The western edge of the Ames limestone was reached by Condit in Meigs county of Ohio, where that rock, still fossiliferous, is rippled and is conglomerate with quartz pebbles. This condition is not unknown in other limestones of the Carboniferous; if verbal statements of geologists, who cannot recall localities, may be accepted, the condition is familiar. The writer is indebted to Butts¹⁰⁴ for specific instances in earlier formations. Shrinkage cracks and wave marks are abundant in marine fossiliferous rocks of Stones River and Black River age in southern Tennessee, where the deposits, he is convinced, are of shallow water origin. In the Cahaba valley of Alabama, on the border between the Bessemer and Montevallo quadrangles, he discovered at the base of the Stones River (Chazyan) limestone, a pebbly bed, which was examined in an area of several square miles. At one locality, the pebbles are comparatively few and occur in a layer never more than 2 feet thick; but elsewhere the vertical distribution is much greater, becoming 20 feet, in which fragments are abundant, while small pebbles occur throughout the higher portion of the bed. The pebbles are of quartz, quartzite and chert, varying in size from three fourths of an inch down. Many are

¹⁰⁴ C. Butts, letter of June 21, 1912.

well rounded, but those which are angular or subangular are quite as abundant. *Maclurea magna* and a considerable number of other forms are present in the limestone containing the pebbles. This locality must have been very near a shore line; there is no evidence to suggest that the shore was precipitous and one must agree with Butts that deposition in shallow water is indicated, although, according to accepted doctrine, the fossils suggest deep water. The presence of fossils in the Chazyan limestones as well as in the Ames and Vanport, where the rock is changing into merely calcareous sandstone, makes clear that the presence of marine fossils is not to be taken as final evidence of deposition in deep water.

The Testimony of the Fossils.—There are few fossiliferous horizons in the Appalachian basin and collections have been made at not many localities. But, if one bear in mind that the areas of marine deposits are comparatively insignificant, the number of collections will appear sufficient.

A systematic collection of Mercer forms was made in the Zanesville-Newark region of Ohio¹⁰⁵ and some notes respecting the fauna of the same horizon in Pennsylvania were given by I. C. White. In the Ohio area there were obtained species as follows: One crinoid, 1 coral, 5 bryozoans, 3 inarticulated brachiopods, 13 articulated brachiopods, 40 pelecypods, 14 gastropods and 2 cephalopods. Raymond¹⁰⁶ has given a list of forms collected by him from the Vanport at several localities in Beaver county of Pennsylvania; it shows 3 corals, 2 bryozoans, one inarticulated brachiopod, 14 articulated brachiopods, 3 pelecypods, 20 gastropods and 3 cephalopods. I. C. White added to this list from Lawrence county 2 crinoids, 1 articulated brachiopod, 7 pelecypods, 5 gastropods and 1 cephalopod. Twenty-three species are common to the Mercer and Vanport in these lists. Probably the Vanport list is incomplete, as a consider-

¹⁰⁵ Clara G. Mark, "The Mercer Limestone and its Associated Rocks in the Zanesville-Newark Region," *Bull. Sci. Labor. of Denison Univ.*, Vol. XVI., 1911, pp. 267-314; I. C. White, *Sec. Geol. Surv. Penn.*, Rep. Q, p. 68; Rep. Q2, p. 61.

¹⁰⁶ P. E. Raymond, "A Preliminary List of the Fauna of the Allegheny and Conemaugh Series in Western Pennsylvania," *Topog. and Geol. Surv. [of Penn.]*, 1911, pp. 83, 84.

able number of the Mercer forms are not recorded, though they have been found in the Conemaugh of Pennsylvania and West Virginia. It is equally probable that the Mercer list is local only, as some forms mentioned in the Palæontology of Ohio are not given.

The first deposit of the Conemaugh is the Uffington shale, which is rich in fossils at some places within northern West Virginia. The important list is that by Meek¹⁰⁷ of forms collected at Morgantown, a few miles south from the Pennsylvania line. There are 4 articulated brachiopods, 8 pelecypods, 11 gastropods, 3 cephalopods, to which Stevenson in later collections added 1 coral, 2 crinoids, 4 pelecypods and 3 cephalopods. The rock is a black shale, more or less ferruginous, the conditions being very different from those of the Vanport and Mercer, yet, in this collection of 26 species made at an exposure of about 25 square feet, there are 14 species in common with the Vanport and 12 with the Mercer. The Brush Creek limestone and associated shales are separated from the Uffington below by the Brush Creek coal and the Mahoning sandstone. Lists from Pennsylvania have been given by Raymond and White and a brief list of forms collected in western Maryland has been published by Martin.¹⁰⁸ The list by Raymond contains 1 coral, 1 inarticulated brachiopod (*Lingula*), 12 articulated brachiopods, 9 pelecypods, 15 gastropods, 5 cephalopods. To these, White adds one pelecypod and Martin adds a crinoid and an articulated brachiopod. Thirteen species are in common with the Mercer and 16 with the Vanport. Omitting the Cambridge, to avoid repetition, one comes to the Ames limestone, which is actually continuous over a greater area than that of any other deposit in the whole column. Raymond's¹⁰⁹ list from five localities on the Pennsylvania railroad, east from Pittsburgh, contains 1 coral, 2 inarticulated brachiopods, 15 articulated brachiopods, 6 pelecypods, 10 gastropods and 4 cephalopods. The inarticulate brachiopods and the pelecypods are rare. Stevenson gave lists

¹⁰⁷ F. B. Meek, "Lists of Carboniferous Fossils from West Virginia," *Third Rep. Regents of W. Va. Univ.*, 1871, pp. 68-70.

¹⁰⁸ P. E. Raymond, loc. cit., pp. 85-87; I. C. White, Rep. Q, p. 34; G. C. Martin, West Va. Geol. Surv., Vol. II., 1903, pp. 280, 281.

¹⁰⁹ P. E. Raymond, loc. cit., pp. 89-92; J. J. Stevenson, Ohio Geol. Surv., Vol. III., 1879, pp. 207, 223.

of forms occurring in Guernsey and Harrison counties of Ohio, where the rock is a fairly good limestone. He found 2 corals, 1 crinoid, 1 inarticulated brachiopod, 15 articulated brachiopods, 2 pelecypods, 7 gastropods and 1 cephalopod. Condit in 1909 published a list from Meigs county, Ohio, which adds two species of articulated brachiopods. Meek's list from near Morgantown is in contrast with that just given, for it shows one species of inarticulated brachiopods, 10 articulated, 12 pelecypods, 7 gastropods, 2 cephalopods, to which Stevenson at a later date added one articulated brachiopod, 6 pelecypods and one gastropod. The contrast is due to the fact that the collection, studied by Meek, was made at a locality where the Ames limestone is obscured in a mass of fossiliferous shales extending downward into the horizon of the Pittsburgh reds. At a mile north, the limestone is distinct and has no pelecypods except *Myalina* and *Aviculopecten*. In comparing these lists with those from earlier deposits, one finds 23 species in common with the Vanport and 24 with the Mercer. The Ames limestone is succeeded in Pennsylvania by shales, at times 70 to 80 feet thick, in which Raymond found marine forms at several levels. They are not abundant, but 2 species of articulated brachiopods, 6 of pelecypods and one cephalopod were recognized and an *Orbiculoidea* was found near the top of the deposit at 75 miles east from Pittsburgh.

It would seem that distribution of the organic types depends often upon the character of the rock. Miss Mack observed that pelecypods are more abundant in the shaly layers and brachiopods are more abundant in the purer limestone. Raymond's lists indicate that brachiopods are very numerous in his Vanport localities, where the limestone is good; it may be that, where White obtained so many pelecypods, the limestone is broken by calcareous shale. The Ames limestone is comparatively pure where Raymond's collections were made and in Ohio it is a good limestone; pelecypods are very rare—6 species are recorded but individuals are very few. Near Morgantown, West Virginia, the Ames yields no pelecypods except *Myalina* and *Aviculopecten*, whereas pelecypods and gastropods are abundant in the associated shale, the latter, at times, making up the greater part of the mass. Brachiopods are less common in these

shales, but they are of the same species as in the overlying limestone and of equal size.

The lists, as has been said, are local; they do not suffice for comparison of faunas at the several horizons; but that is unimportant here. Each locality has been examined with such care as to give a just conception of the manner in which the several groups of organisms occur. It should be kept in mind that fossiliferous beds are not only fewer in number within the Appalachian Pennsylvanian than in the region west from Cincinnati, but also very much less prolific in species and less commonly so prodigal in individuals. These features suggest to the paleontologist that marine conditions in the Appalachian basin were abnormal.

The coelenterates give no information respecting the conditions. Only two species of coral have been found and one of them has no preference for limestone over shale, individuals being equally abundant in both. One of the crinoids has a similar distribution.

Few species of bryozoans have been reported but these abound at several horizons. They are found in pure and impure limestones as well as in shales containing very little calcareous matter. They are characteristic of somewhat sandy shales in the Waverly of northern Ohio. Ulrich¹¹⁰ says that bryozoans of recent time flourish best in water depositing slightly argillaceous limestone—relatively quiet water—and at depths little beyond the zone of violent wave action. The habits of these animals seem to justify the conclusion that the limestones and other beds in which they abound, the Mercer, Vantage and Cambridge, were deposited in comparatively shallow water, probably less than 100 feet deep; and this conclusion is strengthened by the fact that in some localities the area of those limestones was so restricted that violent wave action would be hardly possible.

The brachiopods, at first glance, are less definite. According to Schuchert,¹¹¹ among recent species of inarticulated brachiopods 24 live between high tide and 90 feet; 7 between 90 and 600 feet, and only one at great depths. *Lingula* and *Discina* are unknown below 90 feet but *Crania* and *Discinisca* occur at greater depth. The inarticulated forms have changed comparatively little in character since

¹¹⁰ E. O. Ulrich, *Bull. Geol. Soc. Amer.*, Vol. 22, 1911, p. 252.

¹¹¹ C. Schuchert, *Bull. Geol. Soc. Amer.*, Vol. 22, 1911, pp. 258-275.

their first appearance and, in all probability, as little in their habits. For the most part, they cling closely to the strand in recent times. Articulated brachiopods of the present day require deeper water and 84 of the living 129 species belong between 90 and 600 feet. Rhynchonellids are never found in shallow water; but this was not always the condition, for in the older rocks they often occur abundantly with thick-shelled lingulids in coarse sandstones and mud beds. The terebratulids range from between tides downward. Of all living brachiopods, 81 per cent. are bound to shallow waters, 7 per cent. are found in the deeper waters of continental shelves and only 11 per cent. occur at greater depths.

Applying Schuchert's results to the Appalachian basin, one finds that *Lingula* and *Orbiculoidea* (*Discina* of authors) are common in the dark roof shale of the Middle Kittanning coal bed of Ohio and that *Lingula* is found in several roof shales within Kentucky. It is present at the Brush Creek horizon. *Orbiculoidea* is reported from the Mercer and the Ames, one species being common to both, and the same genus has been obtained from the upper part of the muds and shales following the Ames. These forms are not numerous in the limestones but they abound in some shales. The individuals are seldom more than five eighths of an inch long but that size is excelled only by forms in coarse rocks. Of the articulated brachiopods, the rhynchonellids, which now prefer deep cold water, and the terebratulids, most of which now inhabit the deeper shallow zone, are feebly represented in the Pennsylvanian—perhaps because these brachiopods were little differentiated at that time. Of the other types, practically all belong to families now extinct and one must determine their habits by the record which they have left in the rocks. The productids attained noteworthy size in the later Devonian coarse sandstones, where they are associated often with heavy-shelled *Lingula* or *Discina*. They are abundant in both the pure and the muddy limestones of the Maxville. Eight species of *Productus* are reported from the limestones and shales of the Pennsylvanian within the bituminous region, one being common to all the lists, 2 to four of them, 2 to three, two belonging to the Cone-maugh and one being confined to the Vanport. Five species are found in limestone and shale alike and two are abundant in shale

which contains only a trace of calcareous matter. The Spirifers are represented by two species, one of which is in shale as well as limestone and its size is the same in both. Sandstones with marine forms seem to be few in the Appalachian basin and the fossils are rare; but such sandstones are numerous in the Devonian of that basin. Spirifers of the later type attain great size in the coarse Oriskany sandstone where they are associated with huge *Discina*; while in the later Devonian they are present in the coarser beds of the Chemung, often appearing in great numbers. The athyrids are the same throughout, whether the rock be limestone or shale. A few of the Pennsylvanian brachiopods occur only where the limestone is free from sand or clay, but that proves only that they preferred the cleaner water; it has no bearing on the question of depth, for within a few yards the limestone shades off into calcareous shale. Condit's discovery of the Ames fauna near the western shore line, where the rock is sandy, conglomerate and wave marked, shows that the animals existed in shallow water. Butts's observations on the Ordovician fauna are equally definite. The evidence is so clear respecting the Pennsylvanian brachiopods, that one is tempted to believe about all the genera, as Schuchert has suggested respecting the rhynchonellids, that they were originally forms belonging to shallow water, and that the tendency of so many modern forms to prefer deeper water is a modification due to subsidence of coastal areas. As far as the testimony of brachiopods is concerned, there is every reason to suppose that the marine deposits were laid down in shallow water.

The pelecypods of the Pennsylvanian within the Appalachian basin are allied, for the most part, to families which in recent times have great vertical distribution. Pectens range from 2 to 200 fathoms; Limas from 10 to 150; Arcas from low water to 200; but aviculoid forms seem to go no deeper than 20 fathoms. At the same time, one must bear in mind that, while many genera have great vertical range, there is, in most of them, a large number of species which are confined to water as shallow as that preferred by *Lingula* and *Discina*. It is certain that most of the Coal Measures pelecypods thrived best where the water carried clay or sand and thrived poorly where pure limestone was deposited. Few pelecypods

were obtained from the limestone at the Mercer horizon but they abound in the calcareous shale; the Brush Creek limestone and black shale has abundance of brachiopods and pelecypods, the latter especially numerous in individuals; the Ames limestone has few pelecypods, specimens of the six recorded species being rare everywhere; whereas the underlying shales have yielded 17 species, most of them represented abundantly—and with them are several species of brachiopods. Wholly similar conditions exist in Devonian and earlier formations where pelecypods abound in sandstones and even in calcareous muds but are comparatively rare in the limestones.

Gastropods of the present day have great vertical as well as geographical distribution, but many genera and species of other genera have very limited vertical range. Respecting those of the Pennsylvanian, little can be said. Their mode of occurrence gives little clue to their habits, for many of the species are almost equally abundant in shale and limestone. The migratory tendencies of gastropods makes the evidence of scattered, even that of comparatively numerous individuals of doubtful value; but where a clay shale is crowded with specimens of two or three species, as is the case many times, there is little room for doubt respecting the habitat preferred by those species. One who has made collections at several localities would not hesitate to assert that many species of gastropods found in the Allegheny and Conemaugh preferred to live near the ingress of muddy water.

If one were to conclude from the occurrence of cephalopod remains, he might decide that the character of the water has been a matter of indifference, for, from the earliest appearance of those forms, they have been distributed in limestones, shales and sandstones, sometimes attaining great size in the last. In so far as the Coal Measures of Pennsylvania and Ohio are concerned, the writer has obtained few specimens from the limestones but he has collected very many from the shales. The distribution would indicate that muddy water was preferred. But this inference has no good basis. Cephalopods are migratory; modern types prefer pure water; but after death, the shell freed from the animal may float great distances to be dropped in any kind of bed. The presence and the distribution of cephalopods give no certain information respecting the con-

ditions. At the same time, it does appear strange that, if the older forms preferred clear water, they are found so seldom in the Mercer and Vanport limestones, formed in long estuaries, while they are so abundant in the muds which are associated with the Brush Creek and in those underlying the Ames.

It would appear that the distribution and the habits of invertebrate animals forms lend no support to the belief that the Appalachian basin, during Coal Measures time, was ever covered in whole or in part by deep water. The passage of muddy-water-loving pelecypods and gastropods into the more calcareous and even into the limestone areas, the occurrence of such forms in shale patches, lying within limestone areas with different but interlocking fauna, suggest that in the areas of limestone deposit also the water was shallow, that those were merely estuaries, bordered in great part by lowland areas with very sluggish drainage.

Cornet,¹¹² in discussing the lowest Coal Measures deposits near Mons in Belgium, regards the absence of gastropods, the abundance of pelecypods with byssus, especially of mytiloids, aviculoids and pectenoids, as evidence that the deposit was littoral. Modern conditions on the Belgian coast strengthen his conviction. The abundance of ammonoids might indicate deep water, but this cannot be decisive in the presence of contrary evidence. One can easily understand the presence of cephalopods in littoral deposits, but it would be difficult if not impossible to explain the great abundance of molluscs with byssus in deposits made far off shore. He says that Barrois had come to the same conclusion respecting the alum-bearing shales at Marly, but E. Haug has placed generally among deep sea deposits the shales and fine shaly sandstones with *Goniatites* and *Pseudonoma*, constituting the Culm. While the life indicates littoral deposition, the fine grain of the H la sediment seems to accord better with a certain distance from the shore. But this objection means nothing for, as actual conditions show, the coarseness or fineness of shore deposits depends on features of the area, its lithology, altitude and climate. The coal terrain, excepting intercalations only a few

¹¹² J. Cornet, "Le terrain houiller sans houille (H la) et sa fauna dans le bassin du couchant de Mons," *Ann. Soc. Geol. de Belgique*, Vol. XXXIV., 1906, Mem., pp. 139-152.

meters thick, is formed of very fine sediments. Clay shales make up about 70 per cent. of the column; nevertheless the Upper Coal Measures of the Franco-Belgian basin cannot be regarded as a deposit of the deep sea. He feels compelled to believe that the neighboring areas were lowlands and that the continent was in an advanced stage of peneplanation.

Jukes-Brown had reached the same conclusion respecting the English coal terrain.

Schuchert,¹¹³ in the work already cited frequently, asserts that, during the periodic invasions in the Palæozoic, the depth of water in the Appalachian sea was very shallow, rarely exceeding 200 to 300 feet. On the west shore of Appalachia, conglomerates, sandstone and coarse muds, with rippled surfaces, are common; while in calcareous periods, one finds shrinkage cracks, marking great mud flats inundated periodically with calcareous materials nearly devoid of life. In the New York basin, the northern division of the Appalachian, the later deposits are sands and muds without marine life, though containing some land plants, some fishes and some freshwater bivalves. The sands are often red, oxidized materials in estuaries, dried out by sun and air. The shallowness of the sea is evidenced by the almost endless list of formation names applied by field geologists. These conditions existed at the close of the Devonian.

Ulrich¹¹⁴ in some instances would go farther than Schuchert in limitation of depth. These students had covered a very great part of the United States either by personal observation or by study of collections made by government geologists and others. They agree wholly in asserting that seas caused by ocean invasions were shallow, but Ulrich feels justified in admitting for some extensive areas a less depth than that which Schuchert, with abundant caution, had named as a probable maximum in his general statement. He had examined about 20 marine embayments of Ordovician and Silurian age in the Nashville and Ozark uplifts—the former within the area of Cincinnati and the latter much farther west. His con-

¹¹³ Schuchert, "Palæogeography of North America," pp. 438, 439.

¹¹⁴ E. O. Ulrich, "Revision of the Palæozoic Systems," pp. 361.

clusion is that the depth of water was never more than 100 feet in those localities and generally much less. His studies led him to conclude that the average depth of Palæozoic seas was even less than 200 feet and that none attained a depth exceeding 600 feet.

There is no reason to suppose that the non-marine limestones are other than shallow water deposits; they are sun-cracked and rippled in some extensive areas. Equally there appears to be no valid reason for supposing that the marine limestones are of deep sea origin; at times, they are sun-cracked and wave-marked; at others they are distinctly near-shore deposits; yet the fauna, characterizing them at a distance from the shore, is present and the individuals are of such size as to show that the conditions were not unfavorable. The only ground for asserting that the limestones are of deep sea origin is the time-honored conception that presence of certain groups of invertebrates is proof that the water was deep. This conception itself stands seriously in need of proof.

MODE OF DEPOSITION.

Before taking up the study of coal beds, it is necessary to ascertain, if possible, the conditions under which the deposits already considered were laid down. Three possible hypotheses have been suggested.

The basin may have been a Mediterranean sea, 250 miles wide and more than 800 miles long, 4,000 to 6,000 feet deep, into which streams delivered débris until the whole area was filled.

The basin, originally almost wholly dry land, was brought under water by gradual but interrupted subsidence; inflowing streams formed deltas which eventually filled the basin.

The water-area, during most of the period, may have been comparatively insignificant. The two longitudinal valleys may have had each its own important river, with tributaries, which formed dejection cones, to be remodeled by floods and by meanders of the streams, while the whole region was subsiding slowly though not continuously.

The first hypothesis is altogether improbable. It involves the conception that the surface of the sea within the basin was at tide

level and that the water was excluded finally by deposition of mineral matter on the bottom. Under such conditions, it would be impossible to account for the formation of fossiliferous limestones and shales within narrow well-defined areas at 2,000 feet below the water-surface. It would be impossible to account for the distribution of conglomerates and pebble rocks, almost free from argillaceous matter, over great areas in the central parts of the basin, 100 or more miles from the shore and at a depth of several thousand feet below the surface. It would be impossible to explain the occurrence of sun cracks, ripple marks and clumps of plants *in situ*, which are found at so many horizons throughout the column. It would be almost impossible to discover a source for the material, which has filled this vast basin of not less than 200,000 square miles to a depth of 4,000 to not less than 6,000 feet. The Appalachian land at the north would have been very narrow, for Carboniferous beds, with coal, were forming in New England less than 175 miles away at the east; the lowland of Cincinnati separated the basin from the Indiana region where coal deposits were forming, no more than 175 miles distant; while, at the northwest, the Michigan area was filling, at less distance away. The land area would be insignificant on all sides except due north; but one cannot accept that as the source, unless willing to assign to the Pennsylvanian a duration which would stagger the credulity of even the most generous geologist. The suggestion that the Appalachian basin was bounded at the east by a great fault seems to be inadmissible for there is no evidence that the fault exists. The Appalachian system of folding originated far back in the Palæozoic and continued through the Devonian and Carboniferous. Its faults with insignificant exception are overthrusts toward the west; but such overthrusts cannot explain the origin of the basin, which could be formed, if formed by a fault, only by a normal fault with hade toward the west.

Each of the other suggestions, somewhat modified, would seem competent to explain the phenomena; but this statement is general. In discussing a matter of this kind, one must endeavor to gain a birdseye view of the whole area, for a problem so vast in extent cannot be studied with a microscope. Many details have much

importance for the local observer but are without weight in a discussion of the whole; while there are others, apparently unimportant, of which the importance cannot be exaggerated. The difficulty is to distinguish essentials from non-essentials, for one's convictions long entertained exert much influence. In any case, this personal equation must affect interpretation of the record, so that the student must be content to offer only a contribution, leaving to another the completion of the work. It is necessary first of all to have a knowledge of present conditions.

Fayol,¹¹⁵ in the third part of his work, has discussed the constitution, origin and formation of deltas, as bearing upon the deposit of sedimentary rocks and has given the results of experiments in the extensive settling vats at Commentry. After exposing the errors into which geologists have been led by imperfect observations in too limited areas, he proceeds to show that the lack of horizontality is not necessarily evidence of dislocation, first referring to Wegmann's¹¹⁶ experiments on deposit of sediments upon an inclined surface. Where beds have been laid down on such surfaces, they pass by insensible slopes and curved lines from horizontality to inclinations more or less strong and modeled on the surface below; the same beds, thick in the low parts, become thinner in rising and imbricate with beds previously existing. In discussing delta deposits, one must distinguish carefully between the Alluvial or emerged and the Neptunian or submerged portions. The material may be either coarse or fine and the inclination may vary considerably.

Lake deltas, such as are seen in alpine areas, have abrupt affluents and the material near shore is coarse while fine stuff is beyond. The slope at the upper edge is from 25 to 35 degrees

¹¹⁵ H. Fayol, *Études sur le terrain houiller de Commentry. Lithologie et stratigraphie*," Saint-Etienne, 1887, pp. 356-531. Though the writer dissents energetically from many of Fayol's conclusions, he cannot withhold the expression of admiration for the manner in which that author has recorded every observation, making the work a treasury house of suggestion and information. It can serve as a model. If other observers had followed the same method, one engaged in preparation of a monograph would not have so frequent occasion to lament the folly which led him to begin the work.

¹¹⁶ *Bull. Soc. Geol. de France*, Vol. 7, 1850, p. 187.

but decreases until it is the same with that of the lake bottom. The slope at the shore varies greatly. In Lake Geneva, that of the Thonon delta is 30 degrees, but that of the Rhone is much less. As the delta advances, the river's mouth is carried forward, while the stream meanders and covers the Neptunian beds with alluvium, which is horizontal. This formation of the alluvium is sometimes so slow as not to interfere with vegetation, as in the chief deltas of the Alps, those of the Reuss, Aar and Rhone. Fayol describes some natural and artificial sections of lake deltas as illustrating the amount of transported material: he says that, above the confluence of the Aar and the Thiele, all lake basins have disappeared up to the Jura; alluvium from the streams, the growth of peat bogs and the work of man have converted them into prairies. Marine deltas differ from those of lakes as the waves and tides interfere with regular development. The deltas of great rivers differ yet more; the Neptunian deposits are more extensive and less inclined, there being beds of several thousand square kilometers with inclination of only some centimeters per meter. Little however is known respecting these deltas, information having been obtained from only a few borings. Enough, however, is known to prove that great deltas contain deposits of vegetable matter, that the beds are less coarse and less inclined than those of lacustrine origin. The arrangement of the beds is closely dependent on the agitation of the water, which in turn is dependent on the size of the basin.

After recounting his experiments, which he regarded as amply confirming his conclusions respecting the origin of the Commeny sands, shales and coal beds, Fayol returns to discuss the primitive inclination of sedimentary rocks. As the doctrine of primitive horizontality has had important influence in the formulation of doctrines respecting the formation of coal beds, he thinks useful to examine it to the foundation and to prove its falsity. He cites Steno, Elie de Beaumont and Dufrenoy, Lyell and Credner in favor of the doctrine, following the notes with a long quotation from Lyell¹¹⁷ in which are described the irregular and steeply inclined deposits near Nice, which that author thinks had the present abrupt

¹¹⁷ C. Lyell, "Elements of Geology," sixth ed., New York, 1866, pp. 18, 19.

dip from the beginning. Fayol regards this as an astonishing exhibition of inconsistency on Lyell's part, since the facts contradict Lyell's conclusions respecting original horizontality. The reader can determine for himself, by consulting the original work, how much reason exists for this exultation.

Fayol examines the facts. He asserts that Steno generalized after having examined only the alluvial deposits. The arrangement of pebbles parallel to the bedding is no proof of original horizontality; the slight average slope of the ocean bottom has no bearing on deposits upon lake bottoms, for the latter often have a comparatively steep slope. The average of the Mediterranean bottom is slight, yet deposits at the mouth of the Var have a dip of 25 to 30 degrees. Beds of vegetable matter are buried in the depths of present deltas, and these have been considered as beds formed on the surface above sea-level and carried down by subsidence, in some cases, to a depth of 150 meters; but geologists have reasoned erroneously from local accumulations of mud and peat in certain deltas, for from those they have reasoned to accumulations of hundreds of meters and to widespread oscillations of the surface. In fine, he accepts de Lapparent's conclusions respecting the stability of the earth's crust and fortifies his position by a long citation from that author. He is convinced that he has destroyed two errors: that the vegetable accumulations in delta deposits were of local origin at the surface; that alternations of freshwater and marine deposits are evidence of oscillation of the surface.

It is certain that no one can doubt the accuracy of Fayol's recorded personal observations and many of his conclusions are in full accord with those of other observers in the same field during the last half century. But one must hesitate before accepting some of the broader generalizations; they are clearly based on observations within too limited areas and apparently on a not wholly clear understanding of what observers elsewhere have recorded. His experiments on sedimentation were ingenious, were executed with great skill and perseverance; they excel, in all respects, the earlier investigations by Rozet, Wegmann, Constant-Prevost and others, yet, in reading the record, one is reminded of Hebert's remark that

it is not always possible in experiment to reproduce the complicated conditions existing in nature. It is well to learn the phenomena as recorded by others at some localities mentioned by Fayol.

De Rosemont¹¹⁸ says that between Aspremont and Nice one sees the great mass of pebbles marking the Var delta. He notes some features which appear to have been overlooked by Fayol. This deposit extends northwardly to the rocks of Saint-Martin-du-Var, westwardly to Cheiron and southwardly to the sea. The homogeneous mass is 350 to 400 meters thick and plunges beneath the sea between Aspremont and Cheiron with a thickness of 500 meters. It is rudely stratified and the dip varies from 10 to 30 degrees. This is the delta of the Var, which was formed prior to the Pliocene. It is cut, almost half way to the bottom, by an old valley, now filled with bluish and yellowish clays, holding a Pliocene fauna. Still later, this Pliocene deposit was trenched along its whole length by the present river Var, which flows in a deep channel-way. The phenomena described by de Rosemont show that, under certain relations of land and sea, the first deposit was laid down; that under other relations, the river dug for itself a broad channel-way in the coarse deposit; that under still other relations, the valley was filled with Pliocene muds; and that last of all, the whole mass being once more above sea-level, the river cut its way down in the muds. It may well be that the steep dips referred to by de Rosemont, Lyell and Fayol originated in a way different from that conceived by the last two authors.

The Aar delta, very small, was studied long ago by Martins,¹¹⁹ whose investigation was extremely detailed. The stream enters at Meyringen an alluvial valley, along which it meanders for about 5 miles, until, in approaching Lake Brienz, it divides to form a petty delta, 85 meters wide at the lake shore. Coarse material is dropped at Meyringen and only fine stuff reaches the lake, where it forms a submerged talus. The lake is 8 miles long and a mile and a half

¹¹⁸ A. de Rosemont, "Sur le delta du Var et la période pluviale," *Bull. Soc. Geol. de France*, III., Vol. V., 1877, p. 799.

¹¹⁹ C. Martins, "Note sur le delta de l'Aar, à son embouchure dans le lac de Brienz," *Bull. Soc. Geol. de France*, II., Vol. II., 1845, pp. 118-122.

wide. The slope of the talus is 30 degrees near the shore but, within 300 meters, it falls to 20 degrees. The surface is covered with fine silicious sand, a homogeneous black mud, which also covers the lake bottom throughout nearly the whole extent. The talus must become continuous with the bottom deposit within three fifths of a mile. Martins thinks that the slope of the delta proper is 20 to 23 degrees, but is certain that the deposits are horizontal in most of the area, for Martins found the bottom a level plain.

The delta of the Rhone, at the head of Lake Geneva, was studied by De la Beche,¹²⁰ whose results have been presented summarily by Lyell. The lake is 37 miles long and 2 to 8 miles wide. The depth is more than that of Lake Brienz, varying from 20 to 160 fathoms, but only from 120 to 160 along the middle line. The Rhone enters at the head as a turbid stream but is limpid at the outlet. An old Roman town, at the shore 8 centuries ago, is now a mile and a half inland. The older portion of the delta, above that town, extends 5 or 6 miles and is a flat alluvial plain, little above the stream and covered with swamps. The surface of the submerged cone sinks very gradually and, at a mile and three quarters, merges with the bottom of the lake, which is covered with river mud. Fine and coarse materials alternate in the delta deposit. When snows melt on the mountains, the increased flow brings down sand, mud, vegetable matter and driftwood. In 8 centuries there has accumulated a formation, perhaps 600 to 900 feet thick and nearly two miles long, with strata only slightly inclined. Conditions are somewhat different where a delta is formed by a torrent having great speed and a moderate quantity of water. The depth opposite the torrent of Ripaille is 80 fathoms at half a mile from shore, so that dip of strata in that minor delta must be not less than twice as great as in that of the Rhone, or apparently not far from 10 degrees.

Gilbert's¹²¹ descriptions and figures of the well-dissected deltas

¹²⁰ H. T. De la Beche, *Edinb. Phil. Journ.*, Vol. II., 1820, p. 107; C. Lyell, "Principles of Geology," New York, 1872, Vol. I., pp. 413-415.

¹²¹ G. K. Gilbert, "Lake Bonneville," U. S. Geol. Surv. Monographs, Vol. I., 1890, p. 162.

of the Bonneville area show that the dips of layers are from 15 to 20 feet degrees near the top but they diminish downward, the layers being disposed in sweeping parallel curves.

Dejection cones are merely deltas formed in the air. They are all due to stream transportation, but they differ greatly in form. More than 35 years ago, Gilbert advised that the broad deposits with gentle slopes be termed alluvial fans, and that the term alluvial cones be restricted to forms with steep slopes and formed by the smaller rapid streams. The distinction is important, as confusion of the types in descriptions seems to have caused some misconception, and the steep slopes described by some writers are seemingly regarded as typical of all. Hogard¹²² long ago found a slope of 35 degrees in dejection cones composed of solid and angular fragments. The greater slope is always shown by the less friable material and cones made in air have much steeper slope than those made in water. Surell's¹²³ studies in alpine areas were made in search of means for protecting mountain areas from ravage by rainfall. He found that the slope of a dejection cone depended greatly on the material of which it is composed. Mud usually accompanies torrents and, where abundant, it is the first material gathered. If the flow be thick, the mud surmounts obstacles and in drying, especially if calcareous, it becomes tough, preventing access of air and destroying vegetation. If it carry blocks or pebbles, it cements them and in this way many breccias were formed in the areas examined. The steepness of the slope, on which a deposit may be laid down, depends on fluidity of the mass. Gravels are deposited on slopes not exceeding two and a half per cent.; fragments, 25 centimeters in diameter or side, may be checked on slopes of two and a half to 5 per cent.; while blocks of half a cubic meter come to rest on a slope of 5 to 8 per cent. If the blocks be very large, the current drops them on rapids; in any event they are dropped at the head of

¹²² H. Hogard, "Quelques observations sur les nappes et cônes d'éboulement et sur les lits de déjection des torrents," *Bull. Soc. Geol. de France*, II., Vol. VII., 1850, p. 186.

¹²³ A. Surell, "Étude sur les torrents des Hautes-Alpes," 2d ed., 1870, Vol. I., pp. 37-39.

the fan. These usually fall from the mountains, and the torrents, no matter how strong, cannot carry them far. The fine mud and sand are not deposited along the torrents but are carried out by the rivers to become fertile alluvium. He describes dejection cones made by the Adour, Garonne and other streams, which have become confluent and which are now gashed by diverging currents. In discussing modes of protection against devastation by torrents, Surell says that it is unnecessary to wait until the region has become reforested. "It suffices if the surface be carpeted with grass, brush or shrubs. The herbaceous plants and the brush, as completely as the trees, protect the surface of the soil, divide the streams which tend to ravine it, prevent abrupt concentration of the waters and absorb a certain portion in the spongy humus, which has formed at their foot." He devotes several pages to discussion of this topic and gives a long list of plants which take possession of devastated areas, some of them growing on naked rock.

One who examines only the illustrating figures given in text-books is in danger of supposing that alluvial fans are of limited extent, confined mostly to comparatively narrow river-valleys with abrupt sides; but the conception would be erroneous. Gras,¹²⁴ in writing of alpine diluvium in southeastern France, says that a great area between the Rhone and the first calcareous mountain of the Alps is filled with clay, sand and pebbles. This thick mass extends northward to beyond Dijon and the Saône Valley and follows the Rhone southward to the Mediterranean shore. The chief development is in the Département of Isere, whence it becomes thinner southward. He recognizes a vast dejection cone, or, better, alluvial fan on the Dauphiny plain, whose summit is in the Grand Chartreuse chain and whose base has a radius of 70 to 75 kilometers. The materials came from the mountains at the east and contain the characteristic rocks of Mount Blanc and other areas, so that they have been transported far. The streams have heaped up pebbles to the thickness of hundreds of meters.

¹²⁴ Sc. Gras, "Sur la période quaternaire, dans le vallée du Rhone et sa division en cinq époques distinctes," *Bull. Soc. Geol. de France*, II., Vol. XIV., 1857, p. 207.

Drew's¹²⁵ description of conditions along the upper Indus are equally illustrative. Alluvial fans of tributary streams issuing from the highlands have a radius of about a mile and a slope of about 5 or 6 degrees, the extreme limits being 3 and 8 degrees. There are, however, other fans with steeper slope, but they are not alluvial—they originated as talus. The streams subdivide on the fans, which increase with regular form as each stream yields its contribution. The fans, originally independent, become united. Drew gives a figure representing the conditions along 30 miles, where the fans have become continuous and extend two miles into the valley. The boundaries of the original fans are still recognizable. Rivers cut across the deposits and the tributaries, in lowering the channels, form new fans at their outlets.

The conditions described by Drew resemble those seen along the upper Rhone. There one finds some cones with steep slopes at their head near the wall, clearly of talus origin, for they were formed by streams issuing from hanging gorges, like the very steep deltas in some Italian lakes, described by Taylor.¹²⁶ The high angle of slope reported by some authors must be due to this mode of origin. Along the upper Rhone as well as along the Adige, just as in the western states, the slopes of the greater alluvial fans are usually gentle almost throughout. Even the gigantic landslide, on the Adige near Rovereto, has a gentle slope where cut by the railroad, though covered with huge blocks. The areal extent of the fans depends on the width of the valley and the transporting power of the streams. There would be notable variations in a slowly subsiding area, especially if the subsidence were not continuous.

One may link this type of deposit with that of the great river-plains by a reference to conditions observed on the upper Nile. Falconer¹²⁷ cites Russeger, who says that between Khartoum and Sennaar, not less than 200 miles, the deposits are:

¹²⁵ F. Drew, "Alluvial and Lacustrine Deposits and Glacial Records of the Upper Indus Basin," *Quart. Journ. Geol. Soc.*, Vol. XXIX., 1873, pp. 441-471.

¹²⁶ F. B. Taylor, "Post-Glacial changes of Altitude in the Italian and Swiss Lakes," *Bull. Geol. Soc. Amer.*, Vol. 15, 1904, pp. 369-378.

¹²⁷ H. Falconer, "On the asserted Occurrence of Human Bones in the ancient Fluvial Deposits of the Nile and the Ganges," *Quart. Journ. Geol. Soc.*, Vol. 21, 1865, pp. 372-379.

1. River mud, like the Nile mud of Egypt, containing calcareo-argillaceous concretions.

2. Friable, fine and coarse conglomerate of quartz grains and pebbles, cemented by ancient mud.

3. Ancient Nile mud, indurated, with embedded iron-shot clay, silicious limestone and, in the ferruginous portions, marly concretions.

4. Fine and coarse conglomerate, cemented by ancient Nile mud and calcareo-argillaceous matter. It is very hard.

5. Dark gray freshwater limestone.

The beds are horizontal and 30 to 36 feet deep. Vegetable remains occur throughout, except in the uppermost bed; the whole is of freshwater origin, the fauna consisting of species now living in the Nile, accompanied by some land forms. These deposits are in the region of widespread floods, whose great areal extent is due to vegetation in the river channel, which the river cannot tear out. The type of deposit is different below the first cataract. Newbold¹²⁸ says that at Thebes one can recognize mica spangles from granite of the first cataract, but at Asfet in the Delta, the spangles are so minute that they can hardly be recognized even with aid of a lens. Pebbles are very rare in the delta area; but the composition and texture of the deposit vary according to position, coarse material being confined to the main channels and their borders; fine material alone reaches the Mediterranean.

In examining the great delta regions in search of possible explanation of conditions during Coal Measures times, one must not confine his attention to the lowland areas; he must consider also the alluvial plains extending at times hundreds of miles above the technical head of the delta, even to the region where tributaries bring down coarse materials. The story is continuous from shore to mountains.

The immense plain of eastern China is described¹²⁹ as curving around the mountainous region of Shan-tung and as extending southward from near Peking for about 700 miles with width of 150

¹²⁸ Lieut. Newbold, "On the Geology of Egypt," *Quart. Journ. Geol. Soc.*, Vol. 4, 1848, pp. 341, 342.

¹²⁹ R. K. Douglas, "China," *Encyc. Brittan.*, 9th ed., Vol. V., p. 630.

to 500 miles. The greater part of this plain descends very gently toward the sea and, being generally below the level of the Hoang-ho, it is exposed to disastrous inundations attending the rise of that river. The flood of 1911 is said to have covered an area 45 miles wide and several hundreds of miles long. The plain is the work of the Hoang-ho conjointly with the Yang-tse-kiang. It is a vast swampy area, in great part devoted to rice culture. Pumpelly¹⁸⁰ has shown that the Hoang-ho has shifted its course many times during the historical period. A Chinese work, published in 1705, states that the course of the river was regulated by Yu, which makes probable that diking had been undertaken and the plain placed under cultivation fully 2,000 years before the Christian era began. Pumpelly republished nine charts, showing changes in the channel-way during 3,000 years. The stream is mighty, turbulent, subject to enormous annual increase of volume, due to rainfall on the distant Kuen-Luen mountains, and it has always been a source of terror to the millions inhabiting the plains. Dikes have caused elevation of the stream bed, which, prior to the last great change, was apparently higher than the adjacent areas from Whang-ho to the mouth, a distance of 400 miles. Before that change, which took place about 1850, the river flowed westwardly to the Yellow Sea, entering it south from the Shan-tung peninsula, about 50 miles in the same direction from Pei-chow or about 150 miles north from the Yang-tse-kiang. The breach occurred near Fungpeh in Suchan and the water flowed away to the Gulf of Pechele on the north side of the Shang-tung area. The passage was by way of the Tat-sing river, whose waters were increased to six times their former volume. The new mouth is more than 350 miles west of north from the old one. By 1858, the old mouth was dry; but in 1863, the river had not yet determined its new channel and water still spread over great tracts north from Tsinan, the capital of Shan-tung.

Blanford¹⁸¹ states that the Ganges-Indus-Brahmapootra plain of northern India embraces about 300,000 square miles and is from 90

¹⁸⁰ R. Pumpelly, "Geological Researches in China, Mongolia and Japan," *Smithson. Contr.*, Vol. XV., No. 202, 1866, pp. 46 et seq.

¹⁸¹ W. T. Blanford, "A Manual of the Geology of India," Calcutta, 1879, pp. 391, 394, LX.

to nearly 300 miles wide. The lowest point on the divide between the Indus and the Ganges is 924 feet above tide, but, in fact, there is no dividing ridge between the two systems and a very trifling change would divert the water from one side to the other—and very probably such changes have occurred. No traces of marine conditions appear in upper India since the early Tertiary. There is no proof that the whole of the plain was at any time under water, nor is there any proof that it was not. The Eocene sea occupied the Indus valley to the foot of the Himalayas and extended eastward to Kuchann. But thence to the Gano hills, no trace of marine condition exists. If the Eocene sea occupied the Ganges area, it is strange that no marine forms have been found. The same statement applies to the Brahmapootra plain, which now is in great part too swampy for cultivation.

Medlicott¹²² says that the Lower and Middle Siwalik formations are composed of immensely preponderating sandstone, with occasional thick beds of red clay and rare, thin, discontinuous bands of nodular earthy limestone—the sandstone itself being occasionally calcareous. Conglomerates prevail in the Upper Siwalik and they are often made up of the coarsest shingle, precisely like that in the beds of the great Himalayan torrents. Brown clay occurs frequently with the conglomerate and at times wholly displaces it. This clay, even when pushed to the vertical, cannot be distinguished, in hand specimens, from the recent plains-deposit and no doubt it was formed in the same manner as alluvium. The sandstone of the zone is exactly like the sand forming the banks of great rivers, but is more or less consolidated. The suggestion that the Siwalik hills are merely an upraised portion of the India plains was not wholly misleading. At one time, the mass was supposed to be of marine origin—a relic of the old notion that a water-basin was an essential condition for extensive accumulation of deposits, and that a sea-margin was needed for such a spread of shingle as is found in the Siwaliks. The same opinion prevailed concerning the plains themselves. But the ocean had nothing to do with the matter. The mountain torrents are laying down great masses of shingle and clay on the margins of

¹²² H. B. Medlicott, *ibid.*, pp. 524, 525, 541, 672.

the plains; the thick sandstones and sandy clays of the Tertiary are, in form and composition, similar to the actual deposits of the great rivers. The vast extent of the alluvial fans is illustrated by one example:

"In the range between the Jumna and the Ganges, clays are very subordinate and the conglomerates are formed of the very hardest quartzite pebbles, just like the shingle now found in the great mountain torrents. This portion of the range is, in fact, an ancient diluvial fan of the rivers Tons, Jumna and Ganges. The Jumna, after its confluence with the Tons, now flows very obliquely across the dūn and passes through the outer range far to the west of the point where it leaves the high mountains, having had to double around the immense accumulation of hard materials it had formerly laid down in front of that gorge."

The Indus is forming alluvial plains in several parts of its valley within Ladak. Medlicott asserts that there is no difficulty in distinguishing lake from alluvial deposits. The former are fine laminated and horizontal; but the latter are irregular, coarse and may or may not be horizontal.

The same author,¹⁸⁸ in a later publication, remarks that the whole plain seems to be covered deeply with alluvial deposits, for even at Ambala, in the upper Indus region, a boring has shown alternations of sand, clay and gravel with some calcareous clay. The sands are one to 41 feet thick; the clays, 3 to 40 feet; but the calcareous beds are thin, none exceeding 2 feet. On the Jumna, within the Gangetic area and at about the same distance from the Siwalik or sub-Himalayan range, large boulders were found at 40 feet, whereas the largest fragment at Ambala is only five by two and a half inches and pebbles of moderate size are not of frequent occurrence. It is important to observe that no organic material has been found in the deposits on either side of the divide. Borings and excavations in all portions of the plain find the same alternation of sands and clays. The "technical" head of the Ganges delta, as it now exists, is where the Hoogly is set off, at 170 miles above Calcutta, which is 70 miles from the sea; the nearest edge of the recent alluvial plain is 80 miles west from that city—an immense area of level strata. The submerged portion extends far into the sea and its

¹⁸⁸ H. B. Medlicott, *Rec. Geol. Surv. of India*, Vol. XIV., 1881, pp. 220, 224, 225, 232, 234.

deposits are approximately horizontal. The depth of water in the Bay of Bengal is small, but outside of the delta area, there is a deep depression known as the "Swatch of no ground." All around it, soundings give a depth of 5 to 10 fathoms, but in the "Swatch" that increases abruptly to 300 fathoms. Fergusson,¹⁸⁴ cited by Topley, has shown that this space is kept open by currents, which may have kept it clear while the adjoining area was filling. In that case, the alluvial deposit would be at least 1,800 feet thick. A boring at Calcutta has proved it to be not less than 481 feet.

Lyell¹⁸⁵ relates that at no place in the delta proper or for 400 miles from the sea does one see any gravel, the whole plain of Bengal being overspread with Himalayan mud, homogeneous but becoming more sandy near the hills and occasionally containing abundance of land shells. Those who sail down the river in time of flood see nothing but a sheet of water in every direction, except here and there where the tops of trees emerge above its level. No reference to vegetable matter is made by Lyell or by any other observer to whose work the writer had had access—though the mud is exposed in river cliffs, 80 feet high near Calcutta. Lyell mentions the boring at Calcutta in which peat was pierced at 50 feet. Blanford, in the work already cited (p. 400), says that this peat bed is found at 20 to 30 feet from the surface in all excavations around the city and that it seems to extend under a large area in the surrounding country, having been met with in borings even to 35 miles south-east and to 81 miles east by north. Lyell states that this was considered to be an old soil, carrying a vegetation similar to that of the present Sundurbund. Logs and branches of red-colored wood occur above and below the peat, so little changed as to be identifiable, and they were recognized as the Soondri tree, now prevalent at the foot of the delta. In this Calcutta boring, clay, sand and pebbles were pierced at 120 feet and another forest bed was reached at 380 feet, while the boring ended in beds of pebbles, sands and boulders. The conditions throughout suggest that, before sub-

¹⁸⁴ W. Topley, "India," *Encyc. Brit.*, 9th ed., Vol. XII., p. 736.

¹⁸⁵ C. Lyell, "Principles of Geology," 1872, Vol. I., pp. 476, 477; "The Geological Evidences of the Antiquity of Man," New York, 1871, pp. 336, 337.

sidence began, the area was diversified with hills and valleys, now reduced to a common level by the mud deposit. One is not justified in referring to the evidence respecting the peat accumulations as unimportant; the observations embrace an area greater than that of all the coal basins within central France.

But similar conditions exist elsewhere on the India peninsula. Medlicott¹³⁶ published with comments the notes made by G. E. Ormiston during excavations for a government dock on Bombay island, on the west coast of India. In a space of about 30 acres, 382 trees and stumps were uncovered, of which 223 were erect. Some of the prostrate stems were without roots, but others had been overthrown in place, for the roots were still partly embedded in the soil. The stumps are rooted in a thin soil of decomposed basalt and are surrounded by a stiff blue clay on which rests black marine mud, 4 to 5 feet thick. Stumps projecting above the clay into the black mud have been drilled by *Teredo*; in some cases the holes pass downward through the trunk towards the roots and are filled with indurated clay. Medlicott states that the trees are *Acacia catechu*; two drifted logs of teak wood were found in the clay. This clay deposit must have been made very quietly, for a prostrate stem shows its branches and even delicate twigs in place. The soil was very thin and the roots spread out horizontally; the trees were large, one of the prostrate trunks being 46 feet long. How far the forest extends is unknown, as no investigations were made beyond the excavation of 30 acres.

But while the region of the Ganges and Indus have been subsiding more or less since the late Tertiary, there have been local elevations of no mean extent within recent time; and their character is such as to leave no room for doubting that they had many predecessors. Fergusson¹³⁷ notes the comparatively recent elevation of the Madorpora Jungh, at whose southern extremity the city of Dacca was built. This uplifted area is 75 miles long with an extreme width of 35 miles and a height of 100 feet on the west side toward the Brahmapootra. Fergusson describes in detail the shiftings of

¹³⁶ Records Geol. Surv. of India, Vol. XIV., 1881, pp. 320-323.

¹³⁷ J. Fergusson, "On Recent Changes in the Delta of the Ganges," *Quart. Journ. Geol. Soc.*, Vol. XIX., 1863, pp. 329, 333-350.

the channel-ways in the delta region, which is covered with silt. MacMurdo¹⁸⁸ published in the *Asiatic Journal* an account of the India earthquake of 1819. An extract was published in Edinburgh, which has been utilized by Lyell. This earthquake was felt within a radius of 1,000 miles from Bhooj, central in the Indus delta. The previous depth of the shallow eastern arm of the river was only one foot at ebb tide, but it was deepened to 18 feet; the village of Sindree, farther up the stream, was submerged and a lagoon was formed with area of 2,000 square miles. Immediately after the shock an elevated area was observed at the northeast, where previously there had been a level plain. This, the Ullah Bund, is more than 50 miles long, 16 miles wide and has an average height of 10 feet above the delta surface. The course of the Indus, as Lyell related, was much unsettled during several years, but in 1826 the river threw a great body of water into the eastern arm, which cut through all artificial dams as well as the Ullah Bund itself. The natural section, thus exposed, showed that the upraised land is of delta material. By 1838, the Sindree lagoon had become almost filled with detritus.

The area drained by the Po, the great plain of northern Italy, has received voluminous treatment from many geologists. A summary description of the area was given by Collie,¹⁸⁹ who says that the plain contains 11,000 square miles and that the mountain area, drained by it, is 16,000 square miles. Borings in the plain show that it is covered with approximately horizontal sand, clay and marsh deposits. The river, in spite of the enormous mass of inorganic materials brought down from the mountains, does little toward aggrading the lower channel, as the load is deposited in lakes whence clear water flows. The stream is thoroughly diked from Cremona to the delta marshes, and the dikes are placed at some distance from the channel, enabling the stream, when in flood, to overflow a considerable space before reaching them. This intermediate space is

¹⁸⁸ Captain MacMurdo, "Account of the Earthquake which occurred in India in June, 1819," *Edinb. Phil. Journ.*, Vol. IV., 1821, pp. 106-109; C. Lyell, "Principles of Geology," Vol. II., pp. 98-102.

¹⁸⁹ G. L. Collie, "Basin of the Po River," *Bull. Geol. Soc. Amer.*, Vol. 15, 1904, pp. 566-568.

covered in many places with willows and thick underbrush, so that the current's speed is reduced and there is little erosion of the dikes. The deposits on the plain of the upper Po are irregular and cross-bedded, consisting of cobbles, coarse gravel and pebbles with occasional wedges of sand. At times, local deposits of stratified silt and clay are seen, such as that near Turin, covering 40 acres. The deposits are more regular along the lower Po, much of the material being clay or fine sand, often laminated. In extended exposures, long, flat lenses of sand are shown, which are enwrapped by the finer sediments.

The plain of northern Italy receives drainage and deposits from the Alps and Appenines by way of the Po and its tributaries; from the Tyrolese Alps by way of the Adige; while smaller streams, flowing directly to the Adriatic, contribute their share toward extension of the plain. Taramelli¹⁴⁰ has gathered the information bearing on the development of the plain, with its sands, clays and occasional coral limestones. At the beginning of the Pliocene, it was in great part dry land, for great valleys were excavated, in which gravels were deposited. The topography, in its broader features, was well-defined at that time. During the later Pliocene, the region was invaded by the sea and deposits, termed marine Pliocene, were laid down. These have been recognized in much of Italy, which must have been an archipelago. But at the close of the Pliocene, irregular differential elevation took place, as appears from the altitudes correlated by Taramelli. It is clear that, after the Miocene, a great area was converted into dry land, to be brought again under the sea, but afterwards to be elevated in some localities to 700 meters above that level, while in others it is still below it. These Pliocene beds are the terraces of diluvial deposits.

De Collegno¹⁴¹ has shown the wide extent of pebbly and sandy deposits in northern Italy and the relations of those deposits to the rivers. On the plain of Milan, the pebbles are often consolidated into a conglomerate, which is exposed along the river and in rail-

¹⁴⁰ T. Taramelli, "L'Epoca glaciale in Italia," *Atti Soc. Ital. Progr. Sci.*, Riunion IV., 1910, separate, pp. 5, 6.

¹⁴¹ De Collegno, "Note sur le terrain erratique du revers méridional des Alpes," *Bull. Soc. Geol. de France*, II., Vol. II., 1845, pp. 284-286.

road excavations. He found that, south from Milan, the gravel is too fine for use in maintaining the roads, whereas, north from the city, ample material for that purpose is found just below the surface. From Turin to Verceil, the bowlders rarely exceed 50 centimeters; but, in ascending from Chivasso toward the valley of Aoste, by Ivrée, one finds great blocks of 40 to 50 cubic meters. This deposit is 400 meters thick at Ivrée, where one often sees 100 meters of conglomerate; it is 60 to 80 meters thick on the Adda and some borings on the left bank of the Po have been pushed 60 meters without passing through the detrital mass.

Martins and Gastaldi¹⁴² remark that the alpine diluvium underlying moraine material is composed of pebbles, which decrease in size as one leaves the Alps. At the foot of the mountains they have a diameter of 40 to 50 centimeters, but at Turin they are rarely as large as a man's head. Small and large pebbles are present together and are mingled with sand and gravel.

Tacconi¹⁴³ studied collections from about 100 borings in and around Pavia, which is at the junction of the Po and the Ticino. He distinguished readily between the contributions made by those rivers, for glaucophane characterizes the Po material and staurolite abounds in that from the Ticino. Pebbles and gravels are wanting in the exposed deposits, diluvial in the terraces but alluvial in the valley; in some collections, however, especially in those from the deeper borings, coarse sand and small pebbles are abundant. The usual color of the sands is ashen-gray, but some specimens are yellowish, the tint being due to alteration of ferruginous constituents. These are from different depths and Tacconi conceives that these layers of alluvium may have been exposed to the air for considerable periods before burial under later deposits. The distribution of minerals leads him to suppose that, during the diluvial epoch, the great rivers, descending from the Alps, united in the Lombardy plain

¹⁴² C. Martins et B. Gastaldi, "Essai sur les terrains superficiels de la vallée du Po, aux environs de Turin, comparés à ceux de la plaine Suisse," *Bull. Soc. Geol. de France*, II., Vol. VII., 1850, pp. 587-589.

¹⁴³ E. Tacconi, "Sulla composizione mineralogica delle alluvioni costituenti il sottosuolo di Pavia e dintorni," *Rendic. R. Ist. Lomb.*, II., Vol. XXXIV., 1901, pp. 873-881.

and covered a vast area with water, so as to spread the mingled sediment of many water courses over the whole.

The north-central portion of the Italian plain certainly resembles closely a confluent flood-plain. The Adige emerges from its valley just above Domigiana and, before reaching Verona, it is flowing in the broad plain. It has brought down immense quantities of very coarse material; for many miles it flows on a thick bed of pebbles, derived in great measure from the Tyrolese Alps. At Ala, where the river enters Italy, bowlders, 2 feet in diameter, are not uncommon, but the surface material of the flood plain is not coarse, except along the lines of filled watercourses. West from Verona, along the railroad there is no rock exposure, all is river detritus. At many places, the cobbles are so large that the peasants gather them for construction of fences; pebbles large and small are shown in the railroad excavations between Verona and Milan, but they are in sands; the lines of stream flow are not shown in any excavation visible from the road. The material decreases in coarseness very quickly toward the south. Pavia is about 30 miles south from Milan, but no coarse material is found there; Piacenza is about 40 miles south from Brescia where the deposit is very coarse, but at the former city the materials are fine. The Po has been crowded to the south side of the plain, but it has changed its course many times and the deserted channels are distinct.

Morlot maintained that advance of the plain into the Adriatic has been continuous in spite of long slow subsidence and he asserted that, within the historic period, this subsidence has amounted to 5 feet; but the grounds for his assertion have been disputed. Evidence exists which cannot be disputed, which proves long continued subsidence. Challaye¹⁴⁴ reported that a boring made by Dagousse at Venice on the Piazza-de-Santa-Maria-Formosa passed through 132 meters of sand, clay and peat. Micaceous sand prevailed to the depth of 25 meters and beds of peat were pierced at 29, 48, 85, and 126 meters. He asserts that the peat in these beds is absolutely the same as that forming now at several places within the lagoon. Challaye finds evidence in this boring that, including the growth

¹⁴⁴ C. A. Challaye, *Bull. Soc. Geol. de France*, II., Vol. V., 1848, pp. 23, 24.

on the present surface, five forests have flourished on this spot. Many borings have been made in this immediate area and the evidence is consistent throughout. Tacconi¹⁴⁸ has discussed the record of one, which was driven 197 meters without passing beyond the clays and sands. Well-marked peat beds were found at 18.80, 29.15, 32.80, 46.50, 56.70, 86.80, 129.80, 151.50 and thin streaks down to 165 meters. It is quite possible that some of the very thin streaks of carbonaceous material may be composed of vegetable matter brought down during floods, but the suggestion of similar origin for the thicker deposits, as made by some writers, cannot be entertained. In view of what is known respecting the ability of floods to remove the plant cover, the suggestion must be regarded as pure assumption; the Po of the present day is confined within dikes, yet it cannot sweep the enclosed narrow flood plain clear of willows and underbrush; there is no reason to suppose that the unconfined stream was more efficient. Moreover, the material brought up from the borings is peat, not a mere agglomeration of vegetable material, but peat, such as now accumulates at the surface. Tacconi emphasizes the fact that peat is more abundant in the upper portion of the deposit, the important beds being within 18 and 59 meters; and he notes especially the bed at 18.80, which is 2.6 meters, and that at 29.15, which is 6.25 meters thick, and, like some of the others, contains wood. The lower beds are thinner and increasingly impure, which leads him to suppose that conditions were less stable, that the river courses were changed more frequently in the earlier than in the later stages of deposit. The materials pierced by this boring are mostly fine, only one layer of coarse stuff having been found. The thickest clay bed is 8 meters and the thickest sand deposit is 24 meters.

The Mississippi region has been described so minutely by many authors that only passing reference to some details is necessary here. The delta, as usually limited, begins at a little way above the Red River of Louisiana, but in Tertiary times the water area

¹⁴⁸ E. Tacconi, "Sulla composizione mineralogica della sabbia di un pozzo trivellato al lido di Venezia," *Atti R. Ist. Veneto*, Vol. LXX., 1911, pp. 655-665.

reached almost to the mouth of the Ohio, so that the river bluffs show Tertiary and Quaternary deposits. The broad space, covered with alluvium, extends northward to St. Louis and is continuous thence up the Missouri, which is the main stream, the upper Mississippi being only a tributary. This alluvial area, subject to flood prior to construction of levees, is 40 to 70 miles wide from the mouth of the Ohio to the head of the delta, below which it expands to a maximum of about 130 miles. The area contracts above the Ohio, so that, along the Upper Mississippi and the Missouri, it frequently is less than 5 miles wide.

The nature of the river bed varies. From the head of navigation to the mouth of Maria's river, the Missouri, with velocity of 2.7 miles per hour, flows on loose gravel; but farther down in the loess region the bed is shifting silt. In the lower course of the Mississippi, the river has cut its way to the Tertiary beds, which for long distances are swept clear of later sediments by the current. But samples, taken from the bottom at many localities between the Ohio and the Gulf, show that immense deposits of pure silicious sand and fine gravel, wholly free from river mud, exist in the channel-way. These are found below channel-chutes, at all angles to the direction of flow, sometimes even parallel with it; but they rarely extend from one side to the other. The velocity of the water at such places is too great to permit much deposition but is insufficient to wash away the sand. The materials become finer as the Gulf is approached. The bar at the mouth of Southwest pass is of sand and mud, soft mud being inside and around the shoal, while the surface material is much harder, containing much sand. The bar at the mouth of South pass is chiefly sand with spots of soft mud, but away from the shoal, the bottom is covered with soft yellow and blue mud of the passes.

Studies were made in 1851 to ascertain whether or not material was pushed along by the river. A keg was laid on the bed in such fashion as to retain suspended matter while permitting unimpeded flow of the water. Coarse sand with some clay was obtained at many localities, while at others only coarse sand remained in the keg. Near the mouth of Red River, at the head of the delta, the

samples consisted of small gravel and coarse sand with very little clay. No coarse material is carried beyond New Orleans but pebbles occur in the lower alluvium near that city and the bars at the mouths of the passes show very distinctly the effect of sorting. The source of the coarse material was not determined, but in any event it is certain that the gravels had travelled hundreds of miles.¹⁴⁶

The story has been continuous along the Mississippi since early in the Tertiary. The river has made its valley in the soft rocks forming its bluffs, where successive deposits are exposed. In the later Tertiary as well as in the alluvial deposits, one sees the cypress swamps which at one time were at the surface. The erect stumps and fallen trunks are present, the condition being wholly like that in recent swamps, except that the trees are dead. Forested and buried swamps are numerous and of great extent on the alluvial plain below Red River, but their area has been diminished by drainage and the protection afforded by levees. The buried swamps, supposed at one time to be composed of drifted vegetable matter, are known now to be *in situ*.

It is not always easy to draw the line between delta deposits and those made on flood plains, as is evident from Medlicott's observations on the Indo-Gangetic region. Belt's¹⁴⁷ studies in a portion of the Siberian plain may be taken as complementary to those by Medlicott, for they show how widely coarse material may be distributed by rivers. Leaving Ekaterinburg, he reached the level, sandy region of the steppe within 60 miles and continued his journey in east-southeast direction to Ischim, on a tributary of the Irtisch, where the steppe wall, 80 feet high, is composed of sand without pebbles and partly cross-bedded. Thence to Omsk on the Irtisch, the plain is monotonous but at that city he saw a section showing 60 feet of the steppe deposit, in which the sand, at times cross-bedded, contained lines of pebbles, none larger than a cherry, with here and there broken shells of *Cyrena fluminalis*. At Omsk, he

¹⁴⁶ A. A. Humphreys and H. L. Abbot, "Physics and Hydraulics of the Mississippi River," 1876, pp. 45, 90, 92, 147, 673.

¹⁴⁷ T. Belt, "The Steppes of Siberia," *Quart. Journ. Geol. Soc.*, Vol. XXX., 1874, pp. 490-498.

changed his course and ascended the river 253 miles to Pavlodav. The numerous natural sections had the same structure and composition as at Omsk, except that the pebbles increased in number and size, becoming as large as a walnut within 100 miles. The section of the deposit at Pavlodav is

	Feet.
1. Soil.	
2. Stratified red sand, with lines of small gravel	20
3. Light colored sandy silt	8
4. Coarse, clean sand, with lines of small pebbles and one line of coarse pebbles	15
5. Clayey silt, not laminated; fragments of bed rock in the lower half	6

resting on magnesian limestone. The river at this place flowed on the edge of an alluvial plain 6 miles wide. He crossed at Pavlodav and travelled southwest seeking the source of the pebbles. At about 60 miles from that city, his wheel jolted on the first stone encountered during the ride of nearly 1,000 miles. Thenceforward, angular fragments of quartz were abundant and within a short distance he reached exposures of crystalline rocks. Belt was inclined to believe that ice had impounded the fresh water into a lake, but Ansted had asked, whence came the water to make the freshwater lake of nearly 3,000,000 square miles, in which the steppe deposits were laid down, and also, if there had been the lake, what has become of the water. Ramsay¹⁴⁸ conceived that, if we could imagine the vast flat territory of Siberia with its mighty rivers facing south to a sub-tropical sea, we would have something like the Carboniferous. Coal beds do not indicate old lakes but continental areas, through which rivers meandered.

Reference was made on an earlier page to Kuntze's¹⁴⁹ description of conditions in the Paraguayan region, but other writers have gone into more detail respecting some features requiring consideration here. Church¹⁵⁰ says that a vast area in the Plata region is

¹⁴⁸ G. E. Church, "Argentine Geography and the Ancient Pampean Sea," *Rep. Brit. Assoc. Adv. Sci.*, for 1898, pp. 932-934.

¹⁴⁹ A. C. Ramsay, "Physical Geology and Geography of Great Britain," 5th ed., London, 1878, p. 139.

¹⁵⁰ O. Kuntze, "Geogenetische Beitrage," 1895, pp. 67, 68.

covered to a depth of 20 to 100 feet with a reddish-yellow semi-plastic earth, frequently marly with calcareous nodules, due to percolation of calcareous water from the rivers. No stones or pebbles are seen in this deposit, but it grows more sandy toward the west. Church believes that these Pampean deposits were laid down in a sea, 1,400 miles long and with an area of about 600,000 square miles, this being the region now drained by the Paraguay and its tributaries, the Pilcomayo, Bermejo and Salado at the west, and the Lourenço, Parana and Uruguay at the east. To this area he would add about 115,000 square miles at the northwest, now drained into the Amazon by the Madeira River, the areas being connected by a narrow strait. This inland sea communicated with the ocean near the present outlet of Rio de la Plata, but the area of deposit extended farther southward, almost to the latitude of Bahia Blanca. The Pampean beds have been displaced and made irregular in some places, but they are undisturbed in the southern portion of this Gran Chaco region between the Bermejo and Salado Rivers. Church estimates the present area of the muds at about 400,000 square miles and believes that they were deposited in shallow water. The rivers are all very crooked, have very uncertain channels, at times deserting the old course for a new one several miles away. They frequently divide and subdivide so as to break the plain into narrow but extensive islands.

Kerr¹⁶¹ has described the central part of the plain. The Bermejo River, entering from the west, is 1,000 miles long but very tortuous, the distance in direct line from its source to the Paraguay River being not more than 450 miles. The speed is 4 to 5 miles per hour and an enormous amount of solid matter is carried in suspension—whence its name, "The Red." In flood time, it is almost liquid mud. The rainfall is very heavy and the maxima are marked by inundations covering immense areas to the depth of several feet. Areas subject to inundation are characterized by palm forests, and one may always see on the trees a dark line at 3 to 5 feet above the ground, marking the flood level. The surface layer,

¹⁶¹ J. G. Kerr, "The Gran Chaco," *Scot. Geogr. Mag.*, Vol. VIII., 1892, pp. 74-77.

deposited by the flood, divides during the dry season into pentagonal columns. Remedi, in the same magazine for 1897, says that the Bermejo drops its heavy load, fills its channel and is compelled frequently to take a new direction. Trunks of trees, lodged on the bottom, soon lead to formation of dams and to diversion of the stream.

The Chaco Oriental is north from the Pilcomayo River, which enters the Paraguay near Asuncion, somewhat more than 100 miles above the mouth of the Bermejo. This part of the area was studied by Smith.¹⁵² The Paraguay River, north from Asuncion, is very near the highland at the east, but west from the river the Chaco is always low and the plain extends far inland to the high table land of Bolivia, which is said to fall off abruptly toward the east. The Chaco is covered with water during heavy rains. Above the mouth of the Bermejo, the region is forested, but farther north are great areas with only scattered *Caraua* palms and no other vegetation. In lat. $21^{\circ} 26' 40''$ S., the river issues from a gorge through rocky hills, which, toward the east, are well connected with the Brazilian highlands; but, west from the rivêr, there seems to be a series of isolated hills rising from the Chaco, whose relation to the Bolivian highlands is unknown, as the region has not been explored. Above this gap, known as Fecho dos Morros, vegetation changes, the palms disappear and one sees only open grass land with bushes and a forest fringe on the river banks. These upper lands are covered almost wholly when the river, which rises 50 feet, is in flood. All this flat country from Fecho dos Morros to Villa Maria, a distance of 400 miles, is subject to floods, which are greater toward the north. At the mouth of São Lourenço, the area flooded during high water is not less than 150 miles wide. The whole is a labyrinth of lakes, ponds, swamps and channels in a grassy plain, there being forests only near the river bank. It is more remarkable in this respect than the Amazon flood plains, for even at low water one fourth of the area is covered. When the river is highest, the whole

¹⁵² H. H. Smith in J. B. Hatcher, "Origin of the Oligocene and Miocene Deposits of the Great Plains," *Proc. Amer. Phil. Soc.*, Vol. XLI., 1902, pp. 113-131. The communication by Smith is pp. 128-130.

region is a vast lake with floating grass and weeds, only a few islands remain here and there, on which wild animals find refuge.

Near Bahía Blanca, just beyond the limits of the Pampean deposits, Darwin¹⁸⁸ found pebbles of quartz on the coast which must have travelled 45 miles. The Tertiary beds of Patagonia are capped by a conglomerate, extending northward from the Strait of Magellan about 800 miles with an average width of 200 miles and an average thickness of 50 feet. Its porphyry pebbles came from the Cordillera. The rock was derived from masses falling on old coast lines and on river banks. The country is terraced, which leads Darwin to see in the phenomena the influence of wave action on the rising coast. He describes graphically the clashing of fragments as they are driven along by torrents in flood.

CONCLUSIONS.

That a sea or an ocean is needed for accumulation of thick sedimentary deposits has been long a prevalent opinion among geologists. It is a survival of the period when observation within narrow areas provided a warp of fact to be filled in with a woof of fancy, when cataclysms were thought the rule of nature and modern conditions were believed to be exceptional in the earth's history. It so pervades geological literature that one, in disputing the doctrine, is very apt to employ conventional phrases which concede it. When the study of actual conditions had been prosecuted systematically, when phenomena in great and widely separated areas had been ascertained and compared, it became evident that the accepted doctrine was at least defective. During the last quarter century, intimate study of Quaternary deposits in Europe and America, as well as detailed investigations in physical geography—due largely to the initiative by W. M. Davis in America and A. Penck in Europe—has developed anew the conception that, great as has been the work of ocean forces, that of land forces has been vastly greater. As Ramsay saw for Siberia and Medlicott for India, the activities of rivers in conveying and distributing deposits far from the sea have brought about almost

¹⁸⁸ C. Darwin, "Journal of Researches," New York, 1846. Vol. I., pp. 96, 137, 138, 219.

inconceivably great results. Apparently the first distinct formulation of the new presentation in America was made simultaneously by Barrell and Grabau,¹⁵⁴ each of whom utilized phenomena of the Appalachian basin in illustration. Barrell's elaborate memoir discusses the subject in all its phases and merits careful study. He exhibits clearly the important part which river plains played in the Appalachian history down to the close of the Carboniferous. Grabau lays stress on the progressive overlap away from the source of supply, which, when associated with other facts, becomes an important element of the argument.

Study of the facts presented on the pages of this memoir has forced the writer to a conclusion very different from that hoped for when this investigation was begun.

The widespread horizontality of the Coal Measures deposits, coarse and fine alike, recalls conditions observed on the Siberian Steppe and other river regions. The folding of the beds proceeded from a common cause, lateral pressure applied at the east. The violence of plication decreases with notable regularity toward the west, until in western Pennsylvania and in Ohio, along a line of more than 100 miles, the folds become so gentle that they can be traced only by close study. Dips of more than one degree are unusual, while at times and for considerable distances the dip is barely one half of a degree. The same condition exists in a great part of West Virginia. The regular decrease in steepness of the folds leads to the belief that originally the beds were, to all intents, horizontal throughout the basin, the condition being that observed on the great river plains of comparable extent. The rare occurrence of driftwood in the widespread deposits is characteristic not only of the Coal Measures but also of vast river deposits, those of the Amazon, as described by Brown, and of the Ganges as described by Medlicott and Lyell. The long narrow areas of coarse to pebbly sandstone, often with driftwood, recall the filled valleys of the Sierra, described by LeConte, as well as filled deserted bows on the

¹⁵⁴ J. Barrell, "Relative Importance of Continental, Littoral and Marine Sedimentation," *Journ. of Geol.*, Vol. XIV., 1906, pp. 337, 338, 539-541; A. W. Grabau, "Types of Sedimentary Overlap," *Bull. Geol. Soc. Amer.*, Vol. 17, 1906, pp. 635, 636.

Mississippi and the filled channels so often disclosed when a stream in flood cuts across its "bottom." The distinct evidence of sorting of materials in the red shales, where clay and sand are in dovetailing lenses, as well as in some conglomerates, where hardly enough fine material remains to bind the pebbles, leaves little room for doubt that the work was done by streams moving rapidly in some cases, slowly in others. The pebbles are not flat, such as one may find on a shore, but oval or sub-spherical, river pebbles, and their gradual decrease in size as well as number in certain directions shows that the materials were rehandled many times. The rounded pebbles of coal and carbonaceous shale prove equally with those of quartz and sandstone that the deposits, whence they came, cropped out and were exposed to attack by streams of water. The marine limestones, with one exception, are in definite, long, narrow and comparatively insignificant areas, and pass, at the borders, where those remain for observation, into sandstone, chert or shale, the condition being that of an estuary surrounded by lowland, whose rivers bring a minimum of sediment. The shallowness of the water by which sediment was distributed and the short duration of the flooding are disclosed by wave marks, sun cracks and footprints of animals, occurring at so many horizons, while the moderate depth of the estuaries, in which limestone was formed, is apparent from the shore conditions of the limestone. The testimony of the fauna is confirmatory; that life needed not deep water, for it persisted to the very shore line in Ohio. Unconformability by erosion or by overlap marks the contact of Pennsylvanian with the underlying Mississippian in almost the whole basin, showing that the great part was dry land.

The record appears to show that the Appalachian basin, between the Alps-like Appalachia at the east and the low-lying Cincinnati at the west, was divided longitudinally by the flat-topped and only moderately high Alleghania. The deepest portion of the eastern valley lay close to the foot of Appalachia, whence the surface rose westward almost imperceptibly to the crest of Alleghania. The western valley extended as a plateau with its low line crossing eastern Ohio in a south-southwest direction and deepening southwardly. The thickness of deposits in the two valleys is no index to the difference in altitude of the surface; the eastern valley is coincident with the

ancient trough of great subsidence, where deposits, throughout the Palæozoic, attained great thickness and whence they decrease quickly toward the west. The assertion of greater altitude for the western valley is based on absence of all deposits earlier than those of the latest New River in the northern half of the area.

Each basin had its longitudinal river. That of the east, rising in the present confines of New York, flowed with low gradient for more than 1,000 miles, receiving many tributaries from the bold Appalachia and many, perhaps, unimportant tributaries from the gentle slope at the west. Flowing at first close to Appalachia, it was pressed constantly westward by alluvial fans and cones, which became confluent and finally were modeled into a vast river plain. The main stream was sluggish and often interrupted; during high floods, the surface was covered broadly by a sheet of water and the débris from different streams was mingled. The river in the western basin received no débris-laden tributaries from east or west, except at the extreme north; it was more rapid than that in the east and pushed its coarse materials far southward. Progressive overlaps show that subsidence prevailed throughout the basin until the later stages, when it was confined to the contracting area of deposit; but it was differential and not constant. There were long intervals of slight or no movement during which rivers, reduced to base-level, distributed mostly fine material along their lower reaches. At the close of the Pottsville, the valleys had been filled and Alleghania had become buried; the whole area of deposit was an irregular marshy plain. But the old drainage systems continued until near the close of the Conemaugh and determined the lines of sea invasion; they disappeared only with changes in the topography, induced by the forces which were eventually to obliterate the basin. During the whole of the Pennsylvanian, a very great part of the basin was near sea-level. After the close of the Pottsville, few portions of the area of deposition seem to have been more than 300 feet above tide and there is no reason to suppose that any portion was at any time much more than 100 feet below tide.

The writer has become convinced that one must seek explanation of the phenomena of the Appalachian basin in those of the great river plains of modern times; and the phenomena of the Appalachian basin are those of coal regions elsewhere.

THE FORMATION OF COAL BEDS.¹

IV.

By JOHN J. STEVENSON.

(Read April 18, 1913.)

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THE COAL BEDS.

Coal beds are intercalated between rocks of different composition and apparently of different origin. The deposit may cover only a few square yards or thousands of square miles; its changes in thickness may be abrupt or may be so gradual as to be unimportant in a considerable district; the structure may be variable or it may be

¹ Part I. appeared in these PROCEEDINGS, Vol. L., pp. 1-116; Part II., in the same volume, pp. 519-643; Part III., in Vol. LI., pp. 423-553.

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so constant as to characterize the bed in great areas; the composition of the several divisions may be similar or in great contrast; the relations of a coal deposit to the associated rocks may be so intimate as to be interdependent or the association have all the appearance of accident. One must study these conditions and their interrelations.

EXPLANATION OF TERMS.

Classification of the fossil fuels is foreign to the subject of this work, belonging rather to a study of the origin of coal; here, certain familiar terms are used in a broad sense and the whole series from peat to anthracite is taken to be continuous—at least, from the chemist's point of view. The chemical relations existing between members of the series have been expressed in many ways; but this table from Muck² answers the present purpose:

	C	H	O	N
Woody fiber.....	50	6	43	1
Peat.....	59	6	33	2
Brown coal.....	69	5.5	25	0.8
Stone coal	82	5	13	0.8
Anthracite.....	95	2.5	2.5	Trace

The mineral content is ignored in this comparison. The table like all others, is merely a generalization and the boundaries between groups are arbitrary. The passage from one to another is gradual and in each the variations are extreme.

Peat is the accumulation of vegetable matter decomposed in presence of a constant supply of water and protected from access of oxygen. It occurs in areas of greater or less extent on the present surface or in Quaternary deposits. Plant structure is readily recognized in the newer portions but, in the thoroughly matured peat, it can be detected only by aid of the microscope. Under prolonged pressure, peat may assume the appearance of typical brown coal. Lesquereux,³ cited on an earlier page, saw peat exposed midway in the valley of the Locle, where it is dug. At a little way toward the hills, it is covered with 4 feet of marl and is much changed in ap-

² F. Muck, "Die Chemie der Steinkohle," 2te Aufl., Leipzig, 1891, p. 2.

³ L. Lesquereux, "Quelques recherches sur les marais tourbeux," Neuchatel, 1845, p. 95.

pearance, though still distinctly peat; but on the border of the valley, where the marl is thick, the peat has been compressed to 3 inches and has become a brown coal, hard, fragile and with brilliant fracture. G. M. Dawson⁴ found on Belly river, a bed of interglacial peat, hardened by pressure so as to have the appearance of lignite.

Brown coal or lignite exhibits a more advanced stage of chemical change and is the ordinary type in Mesozoic and Tertiary deposits, though it is not wanting in the Quaternary, for the beds at Dürnten and elsewhere in Switzerland as well as at localities in Bavaria must be accepted in great part as brown coal. At times, vegetable structure is thoroughly well preserved, especially where stems of trees are present; at other times, the whole mass is amorphous, while at still others, both forms occur in a single layer, recalling the condition so often seen in mature peat. Lamination is reported from many localities. The color varies from dingy brown to coal black and the luster from earthy to brilliant, but the streak is brown. Brown coal is not unknown in Palæozoic deposits. The great beds of the Decazeville basin, France, two of which have a maximum thickness of more than 100 feet, show all external characteristics of stone coal, but they contain more oxygen and nitrogen than is found in ordinary brown coal and more than twice as much as is present in air-dried stone coal.⁵ The brown coal from Tula in Russia has been studied by many palæobotanists. In spite of its ancient origin, it approaches very closely to lignites in appearance and composition. Nikitin⁶ states that there are several beds, more or less important, in the lowest part of the Carboniferous and that boghead is associated with the coal. In this connection, it may be well to recall the remarkable observation by David,⁷ which appears to have been overlooked. He discovered in soft fine clay of Carboniferous age thickly matted

⁴ Cited by J. W. Dawson, "Canadian Ice Age," 1892, p. 724.

⁵ N. Saint-Julien, cited by J. J. Stevenson, "The Coal Basin of Decazeville, France," *Ann. N. Y. Acad. Sci.*, Vol. XX., 1910, p. 272.

⁶ S. Nikitin, "De Moskou à Koursk," *Guide des excurs.* VII., Cong. Géol. Int., 1897, XIV., p. 5.

⁷ T. W. E. David, *Ann. Rep. Dept. of Mines, New South Wales*, 1890, p. 229.

layers of undecomposed *Glossopteris* leaves, not brittle but retaining their original substance; soaked in glycerine and water, they can be unrolled and laid flat. A large number of the specimens were mounted and placed on view in the museum of the Department of Mines at Sydney.

Stone coal marks a still greater advance in chemical change. With rare exceptions, it is laminated, black or grayish black, more or less lustrous and with a black streak. In nearly all stone coals, there are alternations of bright and dull laminæ, the Glanz- and the Mattkohle of von Gümbel, which may be extremely thin or several inches thick. Usually, there is little macroscopic evidence of plant structure, aside from the mineral charcoal, mother of coal, fusain, Faserkohle of authors, which resembles charred tissue. This is the ordinary coal of the Carboniferous and it is present in many localities of later Cretaceous age. The difficulty encountered in the effort to define a limit between brown and stone coal is increasingly great, as the determination is of commercial importance in the western United States, especially in areas where both types occur in the Mesozoic. Stone coals have been divided commercially into bituminous and semi-bituminous on the basis of volatile content, but this does not suffice for distinction from the brown coals. The latter have been termed hydrous coals because they contain much water, apparently combined, and break up rapidly on exposure to the air. But many so-called anhydrous coals break up with equal readiness on exposure to dry air. It is quite certain that typical Carboniferous coals have, for the most part, a definite prismatic cleavage and that many brown coals lack that feature, while some have it. Many methods of distinguishing the types have been suggested, but none is satisfactory; the exceptions are too numerous to prove the rule. No hard and fast line between brown and stone coals exists except in generalized tables; but, as a rule, the older coals are more advanced in chemical change than those in later deposits.

Anthracite resembles stone coal in structure and often in appearance, but it is more brittle and more brilliant. The volatile content is small, often approaching a trace. Like the stone coal, it often contains much mineral charcoal, thus showing relationship to the

other members of the series, since mineral charcoal is a common constituent of the brown coals as well as of peat.

The series is continuous. By slow destructive distillation under pressure all can be converted into anthracite. The coal at Decazeville is much given to spontaneous combustion and the operators suffer great loss not only by destruction of the coal but also by conversion of much into a dense brilliant anthracite. The change of brown coal into anthracite by eruptive rocks is a common phenomenon in both Europe and America, so common that anthracite is thought by the great majority of students to be a metamorphic coal.

Beside the ordinary coals, which have so many features in common, there are some which might be termed aberrant forms, the cannels, bogheads, kerosene shale; these, which have been termed sapropelic coals, are minutely laminated, brownish black and have a brownish streak. Ordinarily, they are rich in volatile constituents, which give much more brilliant flame than those from bituminous coal. In mode of occurrence and in some structural features they resemble the organic muds or sapropelites of Potonié, which are found in many ponds and in lakelets within peat swamps. They, like the other coals, are composed of changed plant material, but they frequently contain animal remains.

All coals have more or less inorganic material, the ash or incombustible portion. At times the quantity is insignificant, less than 1 per cent. but it often exceeds that of the combustible matter, in which case the rock is known not as coal but as carbonaceous or bituminous shale.

THE EXTENT OF COAL DEPOSITS.

The areas of individual coal deposits vary from a few square yards to many hundreds of square miles. Those of very limited extent are, usually, outlying patches, occupying spaces eroded in older rocks and they abound in some of the western states, where the coal rests unconformably on beds of Mississippian or even greater age. Hall^{*} described several in Iowa, most of which consist of

^{*} James Hall, Rep. Geol. Surv. Iowa, 1858, Vol. I., pp. 121, 124, 126, 130, 131, 133; A. H. Worthen, *ibid.*, pp. 212, 223, 234.

impure cannel. Worthen found many. They are from 150 feet to 2 or 3 miles in diameter, contain well-defined underclays with more or less coal. In one, the coal dips to the center of the little basin; in another, the coal thickens toward the center; in others, the coal is irregular, but in all the coal thins out in approaching the border. At one locality, marine limestone rests directly on the coal. Bain⁹ has discussed these localized deposits and has explained the concave upper surface of the coal as due to consolidation of the vegetable material.

Similar small basins are numerous in Missouri, directly south from Iowa, and occasionally they are of commercial importance. Swallow¹⁰ says that some contain cannel, others, ordinary coal; but the noteworthy feature is that in all the deposit is thick. In one he saw 20 feet of good coal underlying 6 feet of cannel. Meek examined several in undisturbed Mississippian beds and others which occupied hollows in Silurian limestones. Impure cannel is the prevailing material but he saw good coal in one basin. Later observers have gone more into detail. Potter¹¹ described a basin, only 200 yards in diameter, which yielded 22,000 tons of coal; it had two coal beds, 2 and 16 feet thick. Another, 115 yards in diameter, yielded 3,730 tons; its coal bed, with maximum thickness of 8 feet, thinned away on the borders. One, examined by Winslow, occupies a hollow in the Magnesian (Lower Ordovician) and holds a coal bed, almost 7 feet thick midway, and roofed with 7 inches of clay, on which rests fossiliferous calcareous shale. More remarkable pockets were described by Ball and Smith and were thought by them to occupy "sink holes." In one case, the diameter is somewhat more than 270 feet, while the depth is more than 130. Shale, 38 feet

⁹ H. F. Bain, *Iowa Geol. Surv.*, Vol. VII., 1897, p. 300.

¹⁰ G. C. Swallow, *First and Second Ann. Reps. Geol. Surv. Missouri*, 1855, Part I., pp. 191-193; F. B. Meek, *ibid.*, Part II., pp. 112-114; *Reps. Geol. Surv. Mo.*, 1855-1871, 1873, pp. 132, 149.

¹¹ W. B. Potter, "Preliminary Report on Iron Ore and Coal Fields," *Geol. Surv. Mo.*, 1873, pp. 271-274; A. Winslow, "Preliminary Report on the Coal Deposits of Missouri," 1891, pp. 168-171; S. W. Ball and A. F. Smith, "Geology of Miller County," *Bureau of Mines*, Vol. I., 1903, pp. 100, 105, 107, 108, 111.

thick, is at the bottom and on it rests bituminous coal, 32 feet. The coal in all the pockets is rather impure. Meek thought that the coal beds had been let down by solution of the underlying limestone, but studies by later observers make evident that the accumulations were deposited in preëxisting hollows.

Ashley¹² described a small area occupying a basin of different type, eroded in the Merom sandstone of Sullivan county, Indiana. This is in the upper part of the Coal Measures and is regarded by him as evidence of a land surface. The coal is thickest in the middle of this basin and thins away in all directions toward the border. The lower coal beds in Indiana exhibit a tendency to this basin shape, the thinning of coal toward borders of the "swamps" being a common feature. But higher in the column, the areas increase and at length the coal beds are practically continuous for long distances.

The condition, noted by Ashley in Indiana, prevails in the northern part of the Appalachian basin, where extreme irregularity decreases after the close of the Pottsville, and the coal becomes reasonably continuous in greater areas, so that mining enterprises are attended by less risk. But the irregularity was very great in the Pottsville. Reference has been made in another connection to Roy's description of the mode in which the Sharon coal bed occurs, which confirmed the statements made by Newberry, Read and others in the Ohio reports. The same features characterize the Beaver beds in Pennsylvania, of which Ashburner¹³ says that in the northern counties of the state they occur in "swamps," "swallows" or "sumps," and that they are saucer-shaped; the coal thins to a knife-edge on the hillocks of sand but is reached again when those have been pierced. I. C. White¹⁴ was able to study the vagaries of the Sharon coal bed in a mine with 10 miles of workings. The coal rests on 1 to 2 feet of fireclay, overlying the Sharon sandstone.

¹² G. H. Ashley, "The Coal Deposits of Indiana," 23d Ann. Rep. Geol. Surv. Ind., 1899, pp. 22-24, 532, 633, 666, 909.

¹³ C. A. Ashburner, Sec. Geol. Surv. Penn., Rep. R, p. 53; Rep. RR, pp. 95, 97.

¹⁴ I. C. White, Sec. Geol. Surv. Penn., Rep. Q, pp. 194, 202; Rep. QQ, p. 170; Rep. QQQ, p. 123.

The floor is uneven, characterized by "hills" and "swamps," the coal being 4 to 5 feet thick in the latter but thinning away to almost nothing on the former, which are merely piles of pebble rock, rising at times with a slope of 15 degrees. The "swamps" are depressions among the "hills," which White thinks are due to erosion, as the pebble rock varies from 6 to 25 feet, the least thickness being under the swamps. This condition occurs less commonly in higher beds, but it is by no means rare. The Lower Kittanning, in Lawrence county, rests on an uneven floor of fireclay which has an extreme thickness of 10 feet. The coal often dips into swamps with increased thickness at the rate of one foot to the yard; it decreases usually about one half on the hills. The reports by Chance and W. G. Platt note similar conditions in other coal beds of the Allegheny; these are only too familiar in the Conemaugh.

ARE COAL BEDS CONTINUOUS?

The query at once presents itself, are these petty areas exceptional or are they typical? They are from a few yards to several miles in diameter, and one might expect to find yet larger areas, distinctly limited. The question is of great economic importance and the answer is of equal importance in relation to the problem in hand. Are coal beds continuous or do the names applied to them designate only horizons, marking periods when accumulation of coal took place, so to say, contemporaneously at many places and in extensive areas?

The question has been raised less frequently in Europe than in the United States because the coalfields are of comparatively small extent. But in the bituminous region of the Appalachian generalizations presented long ago still hold in the nomenclature, though some observers have opposed them strenuously. The early surveys were made when the region was thinly settled, when mining operations were unimportant and exposures of coal beds were mostly in small pits opened for local supply. There were few records of shafts, there were no records of borings and there were few graded roads; the section was worked out laboriously from natural exposures and without aid of the instruments now regarded as an

essential part of the geologist's equipment. The writer had as his duty, almost 40 years ago, the work of studying in greater detail extensive areas examined 30 years before by pioneer laborers in the northern part of the Appalachian basin. He has never been able to restrain the feeling that the work of those early geologists bordered on the miraculous—the intuition of Hodge, Jackson, Henderson and J. P. Lesley seems to him almost more than human. Even at the time of revision by geologists of the Second Geological Survey of Pennsylvania, the conditions, though better, were poor enough; dependence had still to be placed mostly upon natural sections, for the great mining industry was still in infancy and deep borings for oil were unknown. The defective conceptions inherited from the preceding generation were accepted and continuity of coal beds was taken as the fact, barren areas being regarded as exceptional. This belief was strengthened by the known distribution of the Pittsburgh coal bed, which appeared to have been proved within an area of not far from 15,000 square miles. But the multitude of shafts, the vast number of oil-well records, the increased number of natural exposures due to railway and road construction have provided data during the last twenty-five years, which compel modification of opinion.

When I. C. White, after study of oil-well records in West Virginia, announced that the Pittsburgh coal is wholly absent from fully one half of the area enclosed within the outcrop, the announcement was received with surprise. Stevenson, nearly twenty years earlier, had reached the conclusion that the Allegheny coal beds, for the most part, were wanting in the interior portion of the bituminous region, but White's study of the well records gave the evidence. There is a continuous area of about 10,000 square miles in which coal accumulation was very irregular from the end of the Pottsville to the close of the Carboniferous. But the irregularity is not confined to the central area; it is characteristic, to a less extent, of the whole region.

The conception of continuity was a normal conclusion from the available facts. A coal bed was generally found almost directly under the Mahoning sandstone, resting on a fireclay which overlay

a limestone. Many times an exposure was incomplete, some portion of the little group was concealed but enough was seen to make recognition definitive. The coal was observed so often that, when its place was concealed, its presence was assumed. The bed was mined at that time near Freeport in Pennsylvania and the deposit was named Upper Freeport. Either coal or very black shale was exposed so often in this position both in Pennsylvania and Ohio that barren spaces were regarded as due merely to petty local conditions and the supposedly continuous deposit was called the Upper Freeport coal bed. In like manner, the other horizons became known as coal beds and widespread accumulation of coal at each horizon an accepted fact, without reference to either quantity or quality of the material.

But detailed study of individual coal beds proves that in all there was great irregularity. The Pittsburgh, Waynesburg and Washington, in the upper portion of the series, approach as nearly to continuity as one may conceive, for they are always present in exposures and records within an area of thousands of square miles; but the Pittsburgh shows remarkable variations in thickness; it thins away to nothing from all sides toward the central part of the area while at times only its underclay remains to mark the horizon. The Waynesburg and the Washington horizons are persistent, coal or black shale being present, but there is often only a trace of coal, while the variations in structure of the deposit are extreme. Some Conemaugh coals are practically continuous, according to natural exposures, in Ohio within an area of not far from 1,000 square miles, but they are rarely seen in Pennsylvania; others are present on the east side of the region and rarely appear on the west side. The Allegheny conditions are similar; one bed attains great commercial importance within an area of perhaps a thousand square miles in Ohio, but in Pennsylvania and West Virginia, it is only occasionally important and it is practically wanting in considerable areas. And the statement is true of other coal horizons. The evidence goes to show that there were periods, longer or shorter, during which proper conditions existed, so to say, contemporaneously in many localities but did not exist in very many others. The

greatest unbroken area, after the close of the Pottsville, in which coal accumulated, was that at the Pittsburgh horizon, the coal having been proved up in an area of approximately 8,000 square miles. Originally it was greater, for erosion has removed much. The Sewanee coal bed of the New River seems to have a great continuous area, but the measured sections are somewhat widely separated; they suffice to prove identity of horizon, but they do not justify either assertion or denial of continuity.

Accepting, however, the extreme conceived area for original extent of the Sewanee or the Pittsburgh, one is compelled to recognize that accumulation of coal was not in process at any time in an area of more than 30,000 square miles and that it never was in process simultaneously in all parts of that area; that at most horizons, conditions were favorable to accumulation in areas of a few square miles to some hundreds of square miles while in perhaps the greater part of the regions the conditions were unfavorable. In fine, that the conditions were very much like those existing to-day. And this has always been the case. The Triassic coals were formed in narrow areas; the inconstancy of Upper Cretaceous coals in New Mexico, Colorado and Utah is proverbial—they are spoken of as lenticular; Tertiary brown coals exhibit the same features, which are equally characteristic of Quaternary deposits as well as of peat accumulations of this period. At all periods, conditions favorable to accumulation of coal have existed in comparatively small areas, more or less widely separated. This will be considered in another connection.

The relation of coal to the immediately adjacent rocks is so intimate that they must be regarded as one: a coal bed consists of the floor, mur, Liegende; the coal, houille, Kohle; the roof, toit, Hangende, each of which must be examined in detail.

THE FLOOR OF THE COAL BED.

Miners, long ago, recognized that coal beds ordinarily have a clay floor or seat, but the fact was announced as generalization first

by Mammatt¹⁵ after his study of the Ashby-de-la-Zouche basin. Logan¹⁶ reached the same conclusion independently, several years afterward, as the result of studies in south Wales. His statements led to a comparison of notes and the conditions seemed to be the same everywhere. The relations of the Illinois coal beds have been cited as evidence that the condition is by no means general, but the citation is an error, for Worthen's¹⁷ remarks are so clear that one is at a loss to comprehend how the error came about. He says

The typical fireclay, the "underclay," "seat," or "mur" is rather fine in grain, somewhat sandy, very light gray to almost black, the tint depending on presence or absence of vegetable matter. Carbonate of iron is almost invariably present, sometimes in very small quantity but many times it is abundant in nodules. Alkalies are comparatively unimportant, though often present in sufficient quantity to unfit the material for firebrick. Ordinarily, the rock is plastic, but occasionally it is hard and non-plastic, a "flint clay." This clay seldom shows lamination and on exposure to the air it breaks up quickly into irregular angular fragments. The remarkable feature is the presence of *Stigmara*, whose rhizomas are often interlaced in very complex manner. Owing to the abundance of the plants, the clay is often termed *Stigmara*-clay; but the presence of that plant is not essential; where *Sigillaria* and *Lepidodendron* are wanting or of rare occurrence, *Stigmara* is absent. It has not been reported from underclays of the Monongahela or higher formations in the Appalachian basin.

The "coal-seat" is not always clay or even impure sandy clay.

¹⁵ E. Mammatt, "Coal Field of Ashby-de-la-Zouche," 1834, p. 73.

¹⁶ W. E. Logan, "On the Character of the Beds of Clay, Lying Immediately Below the Coal Seams of South Wales," *Proc. Geol. Soc. Lond.*, Vol. III., pp. 275, 276.

¹⁷ A. H. Worthen, *Geol. Surv. Illinois*, Vol. I., 1866, p. 59.

"The coal seams are usually underlaid by a bed of fireclay, which varies in thickness from a few inches to ten or twelve feet. This was the original soil on which the vegetation that formed the coal grew, and it is often penetrated by the rootlets of the ancient Carboniferous trees, whose trunks and branches have contributed to form the coal."

Hantken¹⁸ gives a section at a Hungarian locality showing 8 coal beds from 0.15 to 3.10 meters thick, of which four have clay and four have sandstone as the floor. Coal deposits were formed on clay, shale, sandstone or even limestone, the conditions being apparently the same as those observed in the study of peat accumulations. The Triassic coal of the Richmond area in Virginia was long supposed to rest on granite. Taylor¹⁹ mentioned the recognized fact that the coals of that area rest directly on granite, though occasionally a foot or two of shale may intervene. Bosses of granite rise as eminences and interfere with mining. This opinion was shared by W. B. Rogers in 1843 and at a later date by Lyell, who asserted that the lower coal bed is in contact with the fundamental granite. The true condition was ascertained by Shaler and Woodworth,²⁰ who showed that the granite contact is due to faulting and that, normally, there is a notable interval, sometimes 300 feet, filled with barren rocks. There is no *a priori* reason, however, why coal might not accumulate on a granite seat. Chevalier's description of the peat growth on granite and gneiss in the Niger region makes this clear enough.

Cores from diamond drilled holes in the anthracite areas of Pennsylvania indicate in many cases that coal beds of notable importance rest directly on conglomerates or are separated from them by a mere film of clay. The cores show all gradations in the floor from fine clay to conglomerate. Similar conditions exist elsewhere. The hard silicious rock, known as "Ganister,"²¹ is at times in contact with the overlying coal bed in the Yorkshire field. Sections in other British fields show that a sandy floor is a by no means uncommon feature, though clay is the usual material.

Limestone of marine or freshwater origin is frequently the floor

¹⁸ M. Hantken, "Die Kohlenflötze und der Kohlenbergbau in den Ländern der ungarischen Krone," Budapest, 1878, p. 131.

¹⁹ R. C. Taylor, "Memoir of a Section Passing through the Bituminous Coal Field near Richmond in Virginia," *Trans. Geol. Soc. Penn.*, Vol. I., Part II., 1836, pp. 286, 287.

²⁰ N. S. Shaler and J. B. Woodworth, "Geology of the Richmond Basin, Virginia," 19th Ann. Rep. U. S. Geol. Surv., 1899, Pt. II., pp. 424-426, 429, 430.

²¹ A. H. Green, "The Geology of the Yorkshire Coal Field," 1878, pp. 19, 26.

of a coal bed. Several coal beds in the Monongahela and higher formations within the Appalachian basin rest at times on fresh-water limestone or calcareous shale; at others clay or shale intervenes, so that in different parts of the area the same coal rests on clay, shale, sandstone or limestone. Two coals of the Conemaugh in Ohio show similar relations to a marine limestone, sometimes in contact with it, at others, separated by several feet of shale or other material.²² C. Robb in 1876 reported 6 inches of limestone directly under a Canadian coal bed, and J. W. Dawson in 1868 described a coal bed which overlies a bituminous limestone, containing *Naia-dites* and *Stigmaria*, the latter, in his opinion, being evidently in place. Not many instances of coal resting directly on marine limestone are recorded from the Appalachian basin, because, with one exception, the marine limestones are, geographically considered, very unimportant members of the column. Nor is the occurrence frequent in any field, so far as the writer can discover, though there are many localities where the interval is not more than a foot. Worthen states that the Coal 1 of Illinois usually overlies 2 to 3 feet of fireclay, but the fireclay is often absent and the coal rests directly on the St. Louis limestone. This, however, is not of the type under consideration, for the case is one of pre-Pennsylvanian erosion; the Illinois Coal 5 occasionally rests on a nodular limestone and Coal 6 is frequently in contact with the underlying marine limestone. Ricketts has described a number of coal pockets in Lower Carboniferous limestone of England but they do not concern the matter in hand, for they are clearly like the Iowa and Missouri pockets, in cavities eroded when the limestone was above water.

Crampton,²³ however, has given notes which do concern the matter. Presenting the results of studies in East Lothian, Scotland, he refers to the lowest limestone as essentially a coral reef with an abundant marine fauna. Portions of the surface were converted

²² J. J. Stevenson, Sec. Geol. Surv. Penn., Rep. K, 1876, pp. 94, 96, 116, 270, 349; Rep. KK, 1877, pp. 52, 163, 179; "Geology of Ohio," Vol. III., 1879, pp. 183, 211, 224, 240, 256.

²³ C. B. Crampton, "The Limestones of Aberlady, Dunbar and St. Monans," *Trans. Edinb. Geol. Soc.*, Vol. III., 1905, pp. 374-378; "Fossils and Conditions of Deposits, a Theory of Coal Formation," *ibid.*, Vol. IX., p. 74.

into white marl, consisting of pulverized coral. In most places, where the horizon is exposed, a coal bed is seen overlying this reef and often in direct contact with the limestone. Great branching *Stigmariæ* grew upon the rock, following all irregularities of the surface as they pushed their way through the marl. Limestone under brown coal is reported from the Tertiary²⁴ as well as from the Quaternary and it occurs frequently under peat deposits of the Recent period. Evidently, *Stigmaria* cared less for the soil than for other conditions, just as do many plants of this day. The relations of coal to the seat are very like those observed in peat deposits, where the accumulation may begin on clay, sandstone, limestone or even on bare consolidated rock, if only the essential condition of moisture be present. Temperature is not all-important, for peat accumulates as well in the tropics as in the temperates, wherever peat-making conditions exist. It fails in the tropics precisely as it does in the temperates, when the peat-making conditions are absent. The relations were the same in earlier periods, for Wall and Sawkins²⁵ report their discovery of 37 coal beds in the Miocene of Trinidad, of which 5 are workable, with a thickness of 19 feet; and this coal-bearing formation was followed by them on the mainland in an area of 36,000 square miles. And the condition still exists on that mainland. Harrison²⁶ says that tropical peat, known as "pegass," occurs behind the fringes of courida and mangrove in many parts of the low-lying coast lands of British Guiana and that it is from 1 to 10 feet thick, though usually 2 to 4 feet. He pointed out that, on the pegass land, the alternation of wet and dry seasons allowed both marsh and ordinary plants to grow and that considerable areas were covered with forest of the Aeta palm.

Stigmaria is present in a great proportion of the underclays. The manner of its occurrence has been described on earlier pages and only passing reference is needed here. Sorby, Platt and Daw-

²⁴ C. v. Gümbel, "Beiträge," etc., pp. 149-151; O. Heer, cited in "Formation of Coal Beds," these PROCEEDINGS, Vol. L., p. 623.

²⁵ G. P. Wall and J. G. Sawkins, "Report on Geology of Trinidad," London, 1860, pp. 112, 197.

²⁶ J. B. Harrison, "Pegass of British Guiana," *Quart. Journ. Geol. Soc.*, Vol. LXIII., p. 292.

kins have testified that, in the cases described by them, the arrangement of the rhizomas proved not only that the plants are *in situ* but also that the direction of prevailing winds was the same during the Carboniferous as now. The immense extent of roots, spread out in normal attitude, as in the plants described by Adamson, Williamson, Potonie and others, compels those students to assert that no conceivable mode of transportation can explain the phenomenon. The interlacing of the roots, shown by Schmitz, Crampton and many others, is regarded as affording strong confirmatory evidence of *in situ* growth. Many coal beds are divided by clay partings of variable thickness; *Stigmaria*, at times, occurs abundantly in such partings. Robb's remarkable specimen was rooted in such a lens of fireclay. But *Sigillaria* and *Lepidodendron*, to which *Stigmaria* belongs, are not the only coal-making plants; just as peat is composed of many plants or of different assemblages of plants in various parts of the world, so coal in one area was formed of plants unlike those in another. There are great coal deposits containing no *Sigillaria* or *Lepidodendron* and consequently the underclay is without *Stigmaria*.

Occasionally rootlets are found so arranged as to make certain that the materials had suffered no disturbance. Ward,²⁷ visiting the Saint-Etienne coal field after the Geological Congress of 1900, saw many instances in which the finest fibrils of roots of erect *Calamites* passed across the planes of bedding down the conglomerate, which formed the original floor; the condition was regarded by him as incompatible with the slightest movement. Bertrand²⁸ observed rootlets *in situ* in an underclay within the Grande Couche at Decazeville; and the writer saw threads of coal descending into an underclay in the upper part of the Campagnac coal bed of the same basin, which suggested rootlets. Fox-Strangways²⁹ states that he saw rootlets passing downward from the Four-

²⁷ L. F. Ward, "The Autochthonous or Allochthonous Origin of the Coal and Coal Plants of Central France," *Science*, N. S., Vol. XII., 1900, p. 1005.

²⁸ P. Bertrand, in letter of January 15, 1911.

²⁹ C. Fox-Strangways, "Geology of South Leicestershire and South Derbyshire Coal Field." *Mem. Geol. Surv.*, 1907, p. 52.

foot coal into the underclay. D. White, in a letter, says that, during his studies in Kansas and Missouri during 1912, he failed at only one mine to find satisfactory evidence of roots *in situ* in the underclay. At one locality in Kansas, the sandy fireclay contains beautifully preserved interlaced vertical roots while at others in both states absolutely good roots are present.

Bennie and Kidston⁸⁰ found spores abundant in underclays, especially within the first 2 or 3 inches below the coal; they cite two localities in which the lower part of the thin clay is barren while the upper portion contains the forms abundantly.

Underclay without coal is by no means rare. Sometimes it underlies black shale with plants *in situ*; in some cases it alone marks the horizon which elsewhere shows a coal bed. In other cases, it is a "forest bed," marking a locality where conditions did not favor accumulation of plant material or where the coal was removed by erosion. Dawson has described many of these and Grand'Eury says that the phenomenon of vegetable soils is as familiar in the Loire basin as it is in Canada. Strahan⁸¹ has given a recent illustration. In the new South Dock excavation at Cardiff, 11 feet of gravel underlies 19 feet of brown and blue clay with some sand. In this gravel were found several upright stumps, about 2 feet high, "rooted in a black clay with stems, the roots extending down into the red marl."

Boulders have been found in the underclay. Ashley⁸² states that the underclay of Coal IV. is soft and fine but, in places, full of boulders. This is the only American record, aside from an incidental note by Gresley, that the writer has discovered, but he has been assured that waterworn fragments do occur in the underclay. Apparently they are not numerous enough at most places to attract attention and the occurrence may be regarded as infrequent. Most probably, the pebbles were laid down on the river plain prior to

⁸⁰ J. Bennie and R. Kidston, "On the Occurrence of Spores in the Carboniferous Formation of Scotland," *Proc. Roy. Phys. Soc. Edinb.*, Vol. IX., 1888, pp. 102, 103.

⁸¹ A. Strahan, "Geology of South Wales Coal-Field," III., 1902, p. 94.

⁸² G. H. Ashley, "The Coal Deposits of Indiana," 23d Ann. Rep. Geol. Surv. Ind., 1899, p. 543.

deposition of the clay, which filled the interstices, so that they may be sought in thin deposits or at the bottom of those which are thicker.

Underclays are often very light in color and many of them contain little iron and less carbon; but some iron is always present even in the most refractory. There is similar variation in the content of alkalis. The absence of iron is believed to be due in chief part to decaying vegetation. The deep red shales of the Coal Measures contain little organic matter, few traces of plants or animals. That organic acids, formed during decomposition of vegetable materials, give somewhat soluble salts with iron has been known for a long time, as was shown on earlier pages where are recorded the results obtained by A. A. Julien and others. Miller,³³ in describing the Boulder Clay of Cromarty, Scotland, gave a local illustration. On the flat moor upland, where the water stagnates over a thin layer of peaty soil, chance sections exhibit the underlying clay spotted and streaked with grayish-white patches. There is no difference between these patches and the red mass in which they occur, all alike consisting of mingled arenaceous and aluminous particles. The stagnant water above, acidulated by its vegetable solutions, seems to be connected with these appearances. In every case, where a crack gives access to the oozing moisture, the clay is bleached for several feet downward to nearly the color of pipe clay. The surface, too, wherever divested of the vegetable soil, presents for yards together the appearance of sheets of half bleached linen. Dawson³⁴ observes that underclays have the white aspect which one sees in the subsoil of modern swamps, and he thinks that the cause is the same in both cases—the removal or transportation of ferruginous coloring matters by the deoxidizing or dissolving action of organic acids or of organic materials in decomposition.

Stainier³⁵ has taken exception to this statement of the conditions and has shown that of 150 specimens of Belgian underclays, barely a

³³ H. Miller, "The Cruise of the *Betsy*," Boston, 1862, p. 357.

³⁴ J. W. Dawson, *Quart. Journ. Geol. Soc.*, Vol. X., 1854, p. 14.

³⁵ X. Stainier, "Notes sur la formation des couches de charbon," *Bull. Soc. Belge Géol.*, Vol. XXV., 1911, P. V., pp. 73-91.

dozen failed to become distinctly red on burning. Those which failed were mostly sandy and two of them were typical "fire-clays." He has found that carbonate of iron frequently occurs as kidneys in the mur—indeed he regards the presence of such kidneys as in some way characteristic of the mur. The immediate provocation for Stainier's discussion was the statement by Mourlon³⁸ that "the mur represents the soil on which grew the now buried and metamorphosed forests of the coal epoch. The forests then as now had the property of taking away the iron disseminated in the soil." It is certain that Mourlon and Dawson, in their generalized statement, have written with too little reserve, for neither one of them could have intended to assert that vegetation had removed all iron from the clay. One reading Dawson's publications sees at once that he was familiar with the occurrence of clay ironstone kidneys in underclays. Stainier says correctly that, if coal be of *in situ* origin, the iron should be returned to the soil when the trees die; but it is evident that he reasons from conditions existing in an upland forest, which are as a rule very different from those upon which the *in situ* doctrine insists. Vegetation undergoing chemical change in swamps does not disappear but becomes peat; only a very small part of the inorganic matter could find its way back to the mur; it would remain in the peat. The mur is merely the soil in which the vegetation began; before long, the decomposing plant material becomes the soil and all relation to the mur ceases. The conception that trees cannot thrive in or on peat is a curious survival, which retains its place in argument although it is contrary to fact. As has been shown in an earlier part of this work, the plant life of swamps is not confined to mosses and humble plants but it includes large shrubs and great trees. Among the latter are some of the noblest forms on the American continent, which certainly thrive as well in swamps as on drier land. Very many plants cannot live on the acid soil of peat, but there are very many others which cannot thrive on soil of any other type. As will appear on a later page, accumulation of peaty matter makes possible only indirect action on the mur or original soil, and that is due only to the

³⁸ M. Mourlon, "Géologie de la Belgique," Bruxelles, 1880, Vol. I., p. 121.
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sinking of dissolved humic and other organic acids, which reaching the bottom may remove iron and alkalies from the clay as they do from the peat. If the original quantity of iron in the mur was small, all or practically all might be removed; but if large, the greater part would remain. In any event there would be a chemical change and the color would become lighter, though enough iron might remain to become distinct after burning.

The tinting of underclays depends in great measure on the quantity of carbon present. Changes during conversion would remove some vegetable matter, but not much, for drainage would be chiefly along the surfaces of roots, which may account for the lack of a coal crust, so often observed in *Stigmara*. The removal could not be extensive throughout the mass, so that if the original quantity was considerable, the clay would be blackened.

The suggestion has been made that gray or whitish murs are not common and that the tint is not original, for, at some distance from the outcrop, the color is not distinctive. The light-colored English clays, it is stated, have been exploited only along the outcrop, where the passage of pluvial waters would be able in time to remove the coloring substances. How effective this pluvial leaching would be in material so nearly impervious as consolidated underclays, the writer cannot determine. On old outcrops of clays and clay shale at road-sides, he has found little evidence of removal of iron and carbon. There is usually a fixation of the iron while the bleaching, as a rule, is insignificant—usually apparent rather than real and due to disintegration or powdering. It may be that the English clays have been exploited only along the outcrop but the case is different in the Appalachian basin. The tints are not confined to the outcrop. Clays have been mined at several localities in Pennsylvania and Maryland during 30 to 60 years, while in Ohio and West Virginia similar work has been continuous for 60 to 80 years. Very many of the mines work up the dip and are "bone dry" with thick cover, at times hundreds of feet, through which no water passes. Pluvial leaching has not existed there. The clay in these mines at a few feet from the outcrop is like that obtained at 1,000 or 2,000 feet farther inside, with pockets of varying tint and of varying composition—the latter

often so serious that great care must be taken in selection for the manufacture of high grade fire-brick. A similar condition was observed in mines working down the dip, the only difference being that the effects of freezing and thawing were perceptible to a somewhat greater distance. H. Ries has informed the writer that the effect of weathering rarely extends beyond 15 feet in a horizontal bed of clay.

The source of the clays is not always clear. It is true that clay is not always present under coal beds, for those rest indifferently on clay, limestone, shale sandstone or conglomerate, just as modern peat bogs do, so that for present purposes the question of source is of subordinate importance. At the same time, it is not without interest, for in a great proportion of cases, conditions favoring accumulation of coal followed those favoring deposition of clays. Firket's⁸⁷ observations have been cited frequently as showing that atmospheric water can convert shale into plastic clay and in support of the suggestion that underclays may be due to changes after deposit. Near Liège a shaft, 30 meters deep, reached an ancient mine which had been abandoned probably 700 years before. There the succession, descending, was Psammite, 0.95 m.; Gray plastic clay, 0.40 m.; Shale, not measured. The clay is very similar to the refractory clay of Ardenne. The psammite had given way, was broken and atmospheric water was admitted, which gave to that rock a brown tint while it changed the upper part of the shale into refractory clay. At another locality, the psammite in ancient workings had become sandy micaceous clay and the shale had become converted into black clay. Firket concluded that, under some circumstances, shale rocks may undergo considerable alteration *sur place*. The action of true mineral springs is not required to effect change of shale into clay, but infiltration of pluvial waters penetrating the ground across a small thickness of rocks may have an influence. It is unnecessary in that case to have the action extend over a long period in order to change 0.40 meter of shale into plastic clay, for not more than 700 years had passed since the ancient mines were abandoned.

⁸⁷ A. Firket, "Transformation sur place du schiste houiller en argille plastique," *Ann. Soc. Géol. de Belgique*, Vol. I., 1874, pp. 60-63.

The observations by Firket are not without interest but, as he recognized, they have little bearing on the matters at issue here. Shales oftentimes are merely laminated clays and lose their lamination when exposed to the atmosphere. There are many roads in the Appalachian basin which show deep through cuts in argillaceous shale. Less than a century, frequently much less than half a century has passed since the roads were constructed, yet the period has sufficed for conversion of the outcrops into plastic clay. But that is not the question. The Lower Kittanning coal rests on a bed of plastic clay, 10 to 20 feet thick, an excellent potters clay, used in manufacture of various wares along a line of more than 150 miles in Pennsylvania, Ohio and West Virginia; a flint clay at the base of the Allegheny, 5 to 25 feet thick, is utilized at many places along a line of fully 100 miles in Maryland and Pennsylvania. No condition such as that described by Firket seems likely to afford even a suggestion toward explaining the accumulation of such deposits, which, except as to thickness, are typical. Nor can one find sufficient explanation for the small proportion of iron in activities of plant life, since those could affect only the superficial portion. The features seem to be original in the mass and due to the work of atmospheric agencies prior to deposition. Long exposure of rocks causes deep disintegration and decomposition, as has been proved by Russell Crosby and Belt, already cited in another connection. The widely distributed Kittanning clay followed the Vanport subsidence, which had been preceded by a long period of quiet or of local elevation, during which deep valleys were eroded on the west side of Alleghania and, in an extended area, no new deposits were laid down. When the disintegrated materials were removed, the finest clays were deposited by themselves, carrying with them the impalpable humus of the soils. The strange irregularities, exhibited by beds in the closing portion of the Beaver, are evidence of a similarly long exposure for great areas and afford reason for applying the same explanation to the other great deposit. The condition may have been similar elsewhere and may account for clays under coal beds as well as at horizons where deposition of clay was not followed by conditions favoring accumulation of coal.

THE COAL.

The passage from mur to coal is gradual at most localities; but it appears to be rather abrupt where the seat is a sandstone or conglomerate. This latter statement is made with reservation, as the writer has had few opportunities to make determination, since coals with sandstone floors are seldom of economic importance within the areas which he has studied. No reference to the condition appears in the literature to which he has had access; but the records of cores in the anthracite area lend countenance to the suggestion, for in many cases, a mere film of clay separates the coal from sandstone or conglomerate and the coal is good to the bottom. At some localities in the bituminous region, a coal bed is clean apparently to the contact with underclay, but in most cases the bottom coal is so impure as to be unmarketable. For the most part, one finds a transition layer, the *faux-mur*, between coal and clay; it may be very thin or it may be several inches thick, and it may consist of inferior coal or of coaly shale.

In broad areas, where the *faux-mur* is distinct, there is, nevertheless, an abrupt separation of the coal bed from the underlying clay; but this is not original, it is the result of disturbance. One finds this condition even in the western part of Pennsylvania and eastern Ohio, where the rocks vary so little from the original horizontality that the dips on the sides of the low anticlinals rarely reach half a degree and often for long distances are much less. Yet even there one finds that the coal has slipped under the pressure and that the contact between coal and clay is slickensided. This is the familiar condition everywhere, so that one seldom is able to determine the exact relation of coal to mur or the relation between plants of the mur and those of the coal. But the opportunity fell to the lot of Grand'Eury³⁸ during his study of the Loire basin. He says that in coal beds, at their mur and in their more or less shaly partings there are roots belonging to various species and that many a time he had

³⁸ C. Grand'Eury, "Du bassin de la Loire," *C. R. VIII^e Cong. Géol. Int.*, 1900, pp. 531, 532; "Sur les conditions générales et l'unité de formation des combustibles minéraux de tout âge et de toute espèce," *Comptes Rendus*, Vol. 138, 1904, pp. 740-744.

seen rhizomas of ferns and creeping roots of *Cordaites* making part of the coal, thus binding the beds to the vegetation of the mur—which, as he says, contradicts one of his former determinations. The lower portion of the coal in such cases is irregular in structure but the passage from one grade of coal to the other is gradual and the coal throughout is composed of the same plants. His belief is that the running rhizomas at the bottom of the marsh have formed coal in place, along with the fossil humus, which he regards as formation of peat, by which the rooted plants were killed, the stems and adventive roots being found in the coal above.

The thickness of a coal bed is from a film to many feet. Definite coal beds, not more than 6 inches to a foot thick, sometimes mark a horizon over hundreds or even thousands of square miles. A thickness of more than 8 feet is unusual in the bituminous regions of this country but very much greater beds are reported from some fields in Europe. The Grande Couche of les Pegauds in the Commeny basin attains, according to Fayol, a maximum of 12 meters while the main bed of the other subbasin reaches, at one place, 20 meters. The vast deposits at Decazeville are in each case at least 70 feet thick near that city and apparently about 100 feet at a few miles south. Dannenberg gives the thickness of one bed in Saarbruck as 5 meters and of the great bed in the Upper Silesian field as from 10 to 20 meters. The Mammoth bed of the southern anthracite field attains a maximum of 114 feet at the easterly end, including only 9 feet of partings. In this case, as also in that of the great Reden bed of Upper Silesia, the enormous thickness is due to union of several beds by disappearance of the intervening rocks. Coal in any field makes up but a small part of the total section. In the middle division of the Saarbruck measures, there are said to be 132 coal beds, in all 32 or 33 meters thick, within a column of 850 meters; in the bituminous region of Pennsylvania, the column is somewhat more than 4,000 feet and contains perhaps 30 coal beds with total thickness of 110 feet.

VARIATIONS IN STRUCTURE.

A coal bed is apt to vary rather abruptly in structure, local conditions having been as efficient during accumulation of coal as they are now during accumulation of peat. A coal bed may consist of two or more divisions, the benches or bancs, separated by partings, which are often more variable in thickness and composition than the coal itself. In some treatises, these benches are referred to as separate beds—and with good reason, as will appear after consideration of the varying character of the partings and the often contrasting composition of the coal in successive benches. Occasionally, however, definite structure persists throughout a considerable area. Thus the Pittsburgh bed, at the bottom of the Monongahela formation, shows roof division, overclay, breast-coal, parting, bearing-in-coal, parting, brick-coal, parting, bottom-coal.

This structure can be recognized in the northern part of the area along a west-northwest line of not less than 170 miles from the eastern to the western outcrop in Maryland, Pennsylvania and Ohio, exposures being practically continuous for 120 miles. It is distinct in an area on each side of the line not less than 40 miles wide for much of the distance and much wider on the eastern side. Yet even this remarkable bed, when traced beyond the limits given, shows that it too is variable. Bownocker³⁹ has made clear that on the western side, in Ohio, the structure changes abruptly at a little way south from the long west-northwest line. The change first appears in southern Belmont county, where the roof division disappears and the breast-coal becomes irregular. Within a few miles, the bed consists of coal, clay, coal, there being no recognizable trace of the upper 6 parts and the clay parting is often a foot thick, whereas in the typical section the partings are all thin, seldom more than half an inch. The condition, first observed in southern Belmont county, prevails southward on the western side for 90 miles. At some localities, the section resembles that seen farther north but analysis of the parts shows that they are not the same.

³⁹ J. A. Bownocker, Geol. Surv. Ohio, 4th Series, Bull. 9, 1908, pp. 10-12.

I. C. White⁴⁰ has given many measurements of the bed showing that similar changes are found in West Virginia along the eastern border, beginning at a few miles south from the Pennsylvania border. The Roof division is wanting almost at once, but that is due to erosion prior to deposition of the Pittsburgh sandstone, and at times one finds the bed complete where the roof was spared. At a little distance southwest, where the sandstone has thinned away, the changed section is distinct and the bed appears to be merely double. It is divided by "bone" or clay, 1 to 15 inches, and the benches vary greatly in thickness; at some localities the upper one has almost disappeared while at others the lower is almost wanting; here and there the bed has a section somewhat like that at the north but comparison of the parts shows that the resemblance is only apparent. The writer, nearly 40 years ago, thought that the change was merely apparent and that he could recognize all elements of the northern structure to a great distance south from Pennsylvania; but the many detailed measurements recorded by White make that position no longer tenable.

Study of measurements along the northern border of the bed prove a variability which was not considered important by the students who examined that area. W. G. Platt's⁴¹ sections in Indiana county of Pennsylvania show that in the extreme northern outliers along the eastern side, the structure is clear, but the lower members are irregular, becoming indefinite at times, while the Breast-coal increases in importance. Measurements recorded by White and by Stevenson⁴² in Allegheny and in northern Washington county show that in the outlying areas at the north, the structure is usually recognizable but that the bottom and brick are insignificant, the bearing-in not always distinct, while the breast, though variable, is the important portion. These changes are wholly in contrast with those already noted as occurring at the south in both Ohio and West

⁴⁰ I. C. White, *Geol. Surv. West Virginia*, Vol. II., 1903, pp. 168-190; Vol. II. a, 1908, pp. 659, 663, 665, and elsewhere.

⁴¹ W. G. Platt, *Sec. Geol. Surv. Penn.*, Rep. *HHHH*, 1878, pp. 162-164, 27.

⁴² I. C. White, *Sec. Geol. Surv. Penn.*, Rep. *Q*, 1878, pp. 152, 166, 177; J. J. Stevenson, *ibid.*, Rep. *K*, 1876, pp. 275, 277, 285; Rep. *KK*, 1877, pp. 313, 322.

Virginia and indicate a different history for the bed in the two regions, showing that coal accumulation persisted for a much longer period at the north than at the south. The conditions afford no little justification for the recognition of each bench as an independent bed. The irregularities of surface indicated by variations in the lower benches at the north as contrasted with the general regularity of the breast or upper portion show that in all probability the area of accumulation increased landward toward the north by advance of the marsh area. But increasing slate partings of extreme irregularity indicate sufficiently that small streams often flooded the area with muddy water.

The continuous area of the Pittsburgh coal bed was estimated by H. D. Rogers⁴³ at 14,000 square miles, the space embraced within the outcrop. I. C. White,⁴⁴ however, after study of oil-well records of West Virginia and Ohio discovered that the bed is wanting in a rudely triangular space within those states and that the available area is not more than 8,000 square miles. As the coal approaches the central area of fine sandstones and red muds, the structure becomes unrecognizable and the bed thins to disappearance. The constancy of the Pittsburgh coal bed is apparent rather than real.

Abrupt changes in thickness and structure are the rule in all coal beds. They are not startling in the bituminous region, except to those who have invested in mines, since the beds rarely exceed 10 feet; but they are very notable in the southern and middle anthracite fields. At one locality in the former, the Mammoth coal bed has 105 feet of coal in 114 feet of measures; at 8,246 feet toward the east it has only 42 feet in 49 feet; in both the coal is concentrated, there being but ten members in each section; but, within a short distance, one finds 40 feet of coal in 53 feet of measures and the section consists of 43 members.⁴⁵ Variations of this type are reported from all coal areas in the United States and they are commonplace in Europe.

⁴³H. D. Rogers, "An Inquiry into the Origin of the Appalachian Coal Strata," *Reps. Amer. Assoc. Geol. and Nat.*, Boston, 1843, p. 446.

⁴⁴I. C. White, "Stratigraphy of the Bituminous Coal Field in Pennsylvania, Ohio and West Virginia," *U. S. Geol. Surv. Bull* 65, 1891, p. 64.

⁴⁵C. A. Ashburner, "The Geology of the Panther Creek Basin," *Sec. Geol. Surv. Penn.*, 1883, pp. 96, 98.

BIFURCATION OF COAL BEDS.

Parallelism of coal beds seems to be regarded as a fundamental principle by some of those who have discussed the origin and formation of coal beds. It has been the subject of many papers in the United States, based on studies in the Appalachian and Mississippi coal fields. With one exception, the authors rejected the doctrine of parallelism, but most of them recognize that, in some extended areas there is parallelism along definite lines.

The partings between benches of coal beds are usually extremely variable but in some beds they show amazing persistence. The bearing-in bench of the Pittsburgh bed is from 3 to 6 inches thick and is bounded by partings which rarely exceed one half inch; yet these are present under more than 2,000 square miles, changing little in thickness or in composition. Ordinarily they consist of mineral charcoal and almost impalpable inorganic matter, but occasionally they have so little inorganic material that the coal appears to be continuous—but the partings are there and the benches retain their peculiarities. This persistence in character is, however, a strange exception and in most beds the variation is extreme.

The splitting or division of the Mammoth coal bed in the anthracite area has been proved not only by measured sections and drill cores but also by continuous workings, which often extend for many miles. In the northern part of the Eastern Middle, the Mammoth and the next bed below, the Wharton or Skidmore, are in contact, but within a short distance the parting has become 114 feet; in another part of the same field, the interval between the beds increases from 35 to 200 feet, the workings on each bed being continuous; the same beds are but 6 feet apart in the southern part of the Western Middle, but farther south, on the north border of the Southern, the interval increases gradually to 80 feet. The Mammoth itself divides. Near Shenandoah in the Western Middle it is a single bed, 40 to 60 feet thick, but within a short distance it is in 2 and then in 3 "splits" in a vertical space of 150 to 200 feet. In the Southern, the bed breaks up, reunites and breaks up again. Sometimes it is a single bed but within a mile it may be in 2 or 3 splits in a vertical space

of 175 to 214 feet.⁴⁶ The extreme variations in interval have been proved by continuous workings on the several splits. It is impossible to determine the relations of these changes in interval throughout the area, as erosion has been energetic in that contorted region and the coal beds remain only in a few deep troughs.

Illustrations are abundant in Europe. De Serres,⁴⁷ in his description of the little basin of Graissessac, says that the coal beds present great regularity as a whole and preserve their parallelism almost constantly. Nevertheless, one finds remarkable anomalies in some parts of the basin. Coal beds approach each other in some localities while in others they are far apart. At times the beds present the appearance of a fan, especially well shown in the mines of one concession; in some of those in another concession, coal beds 3, 5, 6, are almost united, though in other mines, No. 3 is most frequently at 30 meters from No. 4. When one considers that the whole basin is less extensive than the "outlying area" of Pittsburgh coal in Somerset county of Pennsylvania, he must be interested by de Serres's loyalty to the orthodox doctrine amid trying circumstances. Gruner⁴⁸ remarks that the parting of the Batardes coal bed is from 50 centimeters to 8 meters thick. In the middle portion of the Lower Saint-Etienne stage, beds 1, 2 and 4 coalesce with 3, which is very thick; but at times, 4 is separated from 3 by 24 meters of rock. Beds 3 and 4 are frequently united as are also 1 and 2. The area of this stage is little more than that of a township in one of the western states; according to the map, it does not exceed 40 square miles. Fayol⁴⁹ has shown that the Grande Couche of Commentry is one bed at the east side of the sub-basin but on the west side it is represented by 8 beds in a vertical section of more than 200 meters. Boulay and others have given illustrations from north France.

⁴⁶ The observations on which these statements are based have been summarized in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 17, 1906, pp. 219-221.

⁴⁷ (M) De Serres, "Des terrains houillers du département de l'Herault," *Acad. Sci. Montpellier*, Vol. I., 1850, p. 384.

⁴⁸ L. Gruner, "Bassin houiller de la Loire," Paris, 1882, pp. 212, 220, 225, 226.

⁴⁹ H. Fayol, "Études," etc., p. 22.

Dannenberg⁵⁰ states that the Zach bed of the Zwickau (Saxony) area is usually from 1 to 4.5 meters thick, but in the western part of the field it is represented by 2 beds, separated by 8 meters of rock. At Planitz in the southwest, the Planitzer bed is 10 meters thick and the partings are very thin; but these increase toward the north and the 3 benches are in a vertical space of about 70 meters. He gives illustrations of similar type from other coal fields. The familiar instance is that described by Jukes.⁵¹ The Thick bed near Bilston has about 30 feet of coal in 12 to 14 benches; followed northward, the benches separate quickly, so that within 5 miles, one finds the 30 feet of coal distributed in a vertical section of 300 feet, the several benches being independent coal beds separated by shales and sandstones. The Bottom and the New Mine beds divide in like manner. Instances in other British fields have been described by Dugdale, Howell, Bolton and several other observers.

If one consider coal beds separated by considerable intervals he finds equally interesting variations. The Upper Freeport and the Pittsburgh are separated by 350 feet at the western outcrop in Ohio, but that interval increases gradually toward the east until in Indiana county of Pennsylvania it is 600 feet. The Pittsburgh and the Waynesburg are 166 feet apart at the northern outcrop in Pennsylvania, but that interval increases southwardly to more than 400 feet in northern West Virginia. The increase is regular in the thickness of intervening intervals between the Pittsburgh and Upper Freeport, for, throughout, the Ames limestone holds its place approximately midway between the coal beds; but no such regularity of increase is shown in the interval between the Pittsburgh and Waynesburg. An excellent illustration of this irregularity is shown by comparison of two sections given by W. G. Platt⁵² from Armstrong county, Pennsylvania, which are as follows:

These measurements are about 18 miles apart and the interval between the Upper Freeport and the Lower Kittanning is practically

⁵⁰ A. Dannenberg, "Geologie der Steinkohlen Lager," 1911, pp. 211, 212.

⁵¹ J. B. Jukes, "The South Staffordshire Coal Field," 2d ed., 1859, pp. 18, 19, 25, 26.

⁵² W. G. Platt, Sec. Geol. Surv. Penn., Rep. H5, 1880, pp. 215, 288.

Upper Freeport coal bed.....	7	o	2	6
Interval.....	60	o	54	o
Lower Freeport coal bed.....	1	o	1	o
Interval.....	65	o	35	o
Upper Kittanning coal bed.....	1 to 12	o	1	o
Interval.....	45	o		
Middle Kittanning coal bed.....	4	o	117	o
Interval.....	25 to 40	o		
Lower Kittanning coal bed.....	3	o	3	o
Interval.....	33		25	
Vanport limestone.....				

the same in both, while the intervening intervals show notable variation. If one should group the sections given in Platt's report he would find that while the two coal beds preserve an approximate parallelism, the relations of the intervening beds would be indicated by lines describing very irregular waves. This portion of the Allegheny formation shows the same approximate regularity and the associated irregularity in other parts of the region.

The instance recorded by Jukes⁸³ has always been regarded as exceptionally perplexing. The "Roofs coal" of the Thick bed at Dudley rests on the bench below or is separated from it by, at most, 2 or 3 feet of clay; but in going toward Bilston, one finds the interval increasing, 0, 10, 37, 55, 128, 118 and at length, 204 feet near Bilston—these changes taking place within a mile and a half. Near Dudley one finds the Brooch coal at 95 feet above the "Roofs coal," known there as the "Flying Reed," and 108 feet above the Thick. But where the "Flying Reed" is 115 feet above the Thick it is only 30 feet below the Brooch; so that while the interval between Thick and Brooch has increased from 108 to 147 feet, that between Thick and Flying Reed intervening, has increased from 0 to 115 feet.

The condition is not confined to the Carboniferous. Lipold⁸⁴ found splitting of coal beds by no means unusual in the Triassic. At one locality, four coal beds were seen. The first and third converge in a westerly direction, the interval decreasing from 72 to 18

⁸³ J. B. Jukes, "South Staffordshire Coal Field," pp. 36-40.

⁸⁴ M. V. Lipold, "Das Kohlengbiet in der nordöstlichen Alpen," *Jahrb. d. k. k. Geol. Reichsanst.*, Band 15, 1865, pp. 85, 99-101, 109.

feet. The variation in position is in the lower or first bed, the place of the third remaining apparently unchanged. The third and fourth, on the contrary, converge toward the east and eventually unite. Bifurcation was observed in other beds and in some cases one or more subdivisions thin out to disappearance. The Cretaceous coals of the Rocky Mountain region show the same feature.

Some of the features so marked in coal beds are equally characteristic of peat accumulations. The description by Morton⁵⁵ may be cited as representative; the area has only a few square miles but the conditions are those observed on a grander scale in the great marshes of Holland and Belgium. At one locality Morton saw

Brown and gray estuarine silt	6	0
Upper peat	3	6
Gray estuarine silt	10	0
Lower peat, forest bed	2	0
Boulder clay	2	0

The peat and silt were deposited in depressions; they thin out in approaching the ridges. Sometimes the peat beds unite as they rise on the slopes and occasionally after uniting they become continuous with a surface bed which has never been covered. The lower peat shows many trees *in situ*. The peat about each tree is somewhat higher than that in the intervening spaces. The lower silt contains neither shells nor bones. The upper peat, 1 to 10 feet thick and at times divided by silt, contains no upright stems but there are prostrate stems with twigs and leaves as in a forest. The upper silt is sometimes 20 feet thick, but, there, the upper peat is absent and the silts are continuous. On earlier pages many citations were made, recording irregularities in peat deposits, such as variation in thickness, division or bifurcation of beds, disappearance of "splits" by thinning out, even the phenomenon of the "Flying Reed."

RELATIONS OF THE BENCHES IN COAL BEDS.

The total of coal in the separated splits may be greater or less than that in the undivided bed. The partings in the undivided bed

⁵⁵G. H. Morton, "Further Notes on the Stanton, Ince and Frodsham Marshes," *Proc. Liver. Geol. Soc.*, Vol. VI., 1889, pp. 50-55.

may represent, in time-value, the intervening deposits where the splits are most widely separated—in which case the total thickness of coal may be approximately the same throughout. When a split loses thickness away from the place of union, it may be that subsidence began at some distance from that place and was, so to say, rapid; but where the split thickens, the subsidence was at first extremely slow, permitting accumulation to continue after it had ceased beyond the place of union. Some of the splits increase, others lose in thickness. A study of the benches in each split proves independent history.

One may not regard a coal bed as a single deposit, the result of consecutive deposition, broken only by pretty irruptions of clay or sand. It is the record of accumulation in a given area interrupted by longer or shorter intervals of no accumulation, which are marked by the partings. These intervals in one locality may be synchronous with continued accumulation in another. It is very evident that this accumulation did not begin simultaneously in all portions of the area now marked by a coal horizon and it is equally certain that its termination was not simultaneous throughout. Unquestionably the opening and closing of the work at any given horizon were embraced within a definite period, but one must recognize that only a very small part of the bed may be actually of synchronous origin throughout. Study of the benches of the Pittsburgh coal bed has led the writer to conclude that very little coal accumulated in northern Ohio and much of Pennsylvania until after a notable thickness had accumulated in southern Ohio and in West Virginia. The diminishing importance of the portion below the Bearing-in coal seems to indicate a northward advance of coal-forming conditions. It is equally clear that coal accumulation ceased after the Bearing-in within most of the southern portion, for the Breast is unimportant or absent, whereas it continued long time at the north, as appears from the increasing importance of the Breast in that direction. Changes of similar kind are shown by the Middle Kittanning or Hocking Valley coal of Ohio, which has been studied in detail throughout an area of more than 1,000 square miles, where it has great economic importance. Enough is known to make clear that,

in considering the problem of coal accumulation, one has not to deal with vast areas, since coal never was accumulating at any one time throughout a great basin.

RELATION OF COAL BEDS TO BLACK SHALE.

Coal beds vary in character; frequently coal passes gradually into black shale containing laminae of bright or dull coal; occasionally, the passage is almost imperceptible to the eye, the increase in ash causing no marked change in appearance. It is a common observation that, in the Coal Measures, black shale is almost certain to be replaced with coal somewhere. At the Uniontown horizon, in the Monongahela, one finds usually a thinly laminated black shale containing scales and teeth of small fishes and some laminae of coal; but at many localities within its area of several thousands of square miles, this becomes a coal bed which though impure is of local importance. Any coal bed is liable to show this change. The Buck Mountain bed, near the bottom of the Allegheny in the anthracite area, is worthless within a space of many square miles; the Mammoth bed degenerates westwardly and at times is little better than carbonaceous shale. Coal beds as they approach the border of their area are apt to show a greatly increased number of thin partings, usually mud but sometimes sand. Not rarely lenses of sand are intercalated, which may be of considerable extent. Such changes seem to indicate proximity to upland, whence streams came loaded with sediments. They suggest conditions like those which are seen within five or six miles west from New York, where one finds many times a small area of clean peat surrounded by impure material containing layers of mud.

The origin of the black shale is not always clear, but it is a sediment. The carbonaceous matter, in some cases, came in with the sediments as plant fragments, but in others it came rather from animal matter. An illustration of the former condition is found in the work by Scott,⁸⁶ who made dredgings in Lakes Ness, Oich and

⁸⁶ T. Scott, "The Lochs of the Caledonian Valley," *Scot. Geogr. Mag.*, Vol. VIII., 1892, pp. 94, 95.

Lochy for the Fishery Board of Scotland. In Ness, the dredge was filled with fine mud containing fragments of peaty matter and pieces of partially decayed wood. Some exuviae of entomostraca were present but no living specimens were observed. The same condition was found in the other lakes where no attempt was made to determine the thickness of the deposit. In these lakes, the water is free from mud and is dark brown, owing to dissolved organic matter from peat. The streams descend from the Highlands, but the region is protected from erosion by a cover of peat, so that only very fine silt is brought down. The brown waters pass out to the sea and the dissolved materials are not precipitated in the lakes.

The presence of vegetable remains along with those of marine animals in many black shales is by no means proof that the water was shallow nor is the association in any sense evidence that the water was deep. The observations by Agassiz⁸⁷ have been cited many times in this connection as though they contain the final argument. In reference to dredgings in the Caribbean sea he says, that the contents of some of the trawls would have puzzled a palæontologist; there were deep water forms of crustaceans, annelids, fishes, echinoderms and sponges, mingled with mango and orange leaves, branches of bamboo, nutmegs and land shells, both animal and vegetable forms being in great profusion; so that it might be difficult to decide whether one were dealing with a land or a marine fauna. Such a trawl from a fossil deposit would naturally be explained as representing a shallow estuary surrounded by forests; yet the depth may have been 1,500 fathoms. The large quantity of vegetable matter, thus carried out to sea, seems to have a marked effect in increasing locally the number of marine forms.

Whether or not any palæontologist would have reached the conclusion suggested for him by Agassiz is scarcely open to dispute; the palæontologist's answer to the query would be unequivocal and thoroughly emphatic. Commingling of marine and land elements occurs in shallow as well as in deep portions of the Caribbean, with

⁸⁷ A. Agassiz, "Three Cruises of the *Blake*," *Mem. Mus. Comp. Zool.*, Vol. XIV., p. 291.

the distinction that in the latter there are the forms known to be characteristic of deep sea zones only. But no such problem as that imagined by Agassiz presents itself in the Coal Measures—though there are those who believe the contrary. Respecting the marine forms of the Coal Measures time one may assert positively nothing beyond the fact that they are closely related to marine types. There is no evidence to prove that they preferred deep water but there is abundant evidence to show that they had no objection to dwelling in shallow depths; it is sufficiently clear that limestones carrying the typical forms were deposited at many localities where every feature indicates shallow water and close proximity to a shore. This matter has been considered in an earlier part of this work, but it may be well to present additional notes here.

D. White⁸⁸ during the summer of 1912 found evidence of presumably shallow water deposition of some Coal Measures limestones in Oklahoma; Udden has described a brecciated marine limestone near Peoria, Illionis. Ashley⁸⁹ found near Merom in Indiana 2 to 8 feet of conglomerate, consisting of shale, sandstone and coal pebbles, bedded in calcareous matter and resting on 2 to 4 feet of marine limestone. This conglomerate underlies the great Merom sandstone. A stream flowing over the outcrops entered the sea and dropped its load of coarse material into the unconsolidated upper portion of a limestone containing *Productus* and other marine types. As the conglomerate is coarse, it must have been dropped at once when the stream entered a body of water. The Ames limestone is impure, conglomerate but fossiliferous at a locality in Meigs county of Ohio, as recorded by Condit; on the extreme western border in Muskingum county of the same state the Ames is shaly and coarse grained, showing none of the characteristics observed farther east, but it is fossiliferous; in Carroll, on the northwest border, that limestone on the extreme outcrop is very impure, coarse grained and very like sandstone; at a short distance farther east it is more like limestone but at a mile farther it is earthy and disintegrates on exposure. At these localities, one is very near the original shore, where the water

⁸⁸ Letter of October 25, 1912.

⁸⁹ G. H. Ashley, "Coal Deposits of Indiana," p. 908.

was shallow and far from clean, but the characteristic fossils persist to the last exposure of the horizon. Bownocker has noted a number of localities in Meigs, Gallia and Lawrence counties of Ohio, all on the western border, where this limestone is impure, argillaceous, ferruginous or sandy, yet the fossils persist. I. C. White found the same conditions along the northern border in Pennsylvania. Hennen⁶⁰ reports that in Harrison county of West Virginia, where one approaches the southern limit of the Ames limestone, the rock is an impure limestone, often represented only by dark limy shale but always containing the same marine fossils. The Conemaugh formation has other marine limestones which are brecciated at numerous localities. In some cases the shells are broken as on a shore.

THE OCCURRENCE OF CANNEL.

The cannels and bogheads differ from true coals not merely in structure and composition but also in their mode of occurrence. Cannel is invariably a local deposit, in the extreme sense of the term, though conditions favoring its formation existed more frequently at some horizons than at others. Many of the small isolated basins in Iowa, Missouri and even in Pennsylvania contain only impure cannel, but ordinarily the mineral forms part of a coal bed, the relation being intimate. Invariably, the deposit is saucer-shaped, as though occupying a depression in vegetable matter previously accumulated. White⁶¹ has described a cannel of much commercial importance, though it is confined to only one estate; the mass has a maximum thickness of 12 feet and thins away to nothing in all directions. The changes are exhibited in extensive workings. Platt⁶² examined, in Armstrong county of Pennsylvania, three disconnected patches of cannel at the Upper Kittanning horizon. The space between these is occupied by ordinary coal. In each, the cannel is from 0 to 8 feet thick; the bottom bench of the coal bed is bituminous and it is depressed with the thickening cannel, the slope of the

⁶⁰ R. V. Hennen, W. Va. Geol. Surv., County reports, 1912, p. 251.

⁶¹ I. C. White, Sec. Geol. Surv. Penn., Rep. Q, pp. 213, 232, 258, 259, 268.

⁶² W. G. Platt, *ibid.*, Rep. H5, p. 176.

upper surface being from 5 to 22 degrees; but the top bench, also bituminous, rests on the horizontal surface of the cannel and is regular throughout, as is also the roof, both showing only the insignificant dip characterizing the region. In Pennsylvania, one rarely finds cannel at the bottom of a coal bed, but that condition occurs occasionally in West Virginia and it is not infrequent in Ohio. Some coals of the Beaver within Ohio and Kentucky have considerable areas of cannel and are spoken of as cannel beds; but even in those the features are the same as in others, excepting as to extent. The story is the same in all areas. Hull has shown that the celebrated Wigan deposit in Lancashire is saucer-shaped; Green found the same condition in the Yorkshire deposits; David, Mackenzie and Wilkinson have recorded many observations showing that the Kerosene shale of New South Wales has similar distribution. The phenomena are familiar in modern swamps.

DISTRIBUTION OF COAL IN RELATION TO THE ACCOMPANYING ROCKS.

The distribution of coal seems to be related in some way to the character of the associated rocks. In the southern and middle anthracite fields, the coal beds are thick at the northeast, where coarse rocks most abound, and become unimportant at the west, where coarse rocks are less abundant. In the Pottsville of those fields, there are thick coals with pebbly rock above and below, though in most cases there is some shale, often very thin, above or below the coal. In the bituminous region, coal beds of the Allegheny and higher formations appear to have accumulated chiefly on the borders of that region—not as continuous bands, but at definite horizons. They thin away and the horizons become indefinite as one approaches the central area, in which fine materials prevail; yet even there, coal was formed in thin irregular deposits at widely separated localities; and these petty accumulations seem to be at or near horizons which are well defined elsewhere. Coal-making conditions did not exist for any considerable period or in any considerable area within the region of fine-grained rocks.

The same relation has been observed in other countries.

Phillips,⁶⁸ referring to his studies in Yorkshire, states that toward the southwest the limestones thicken, while sandstones and shales become thin. The sandstones thicken toward the north, while shales thicken toward the west, in which direction certain sandstones and limestones vanish. With those sandstones, the coals also vanish. Where the sandstones thicken and grow numerous, toward the north, in which direction the limestones change from an undivided mass to many members, the coal beds augment in number and in thickness. A similar condition is apparent in eastern Oklahoma.

Coal beds seem to be wholly wanting in the Mississippi limestones of the Appalachian basin. Their absence from this mass, at times more than 2,000 feet thick, including the calcareous shales, can hardly be due to lack of vegetation on the land, for the underlying Pocono or Logan sandstone and shales show definite coal beds from central Pennsylvania to Wythe county of Virginia, a distance of not less than 400 miles; while the sandy division of the Chester, equivalent to the highest part of the Mississippian, contains thin coal beds at many places west from the old Cincinnati land. The writer has not been able to make sufficient study of conditions elsewhere to justify him in offering a generalization; but in the Appalachian basin, every observation indicates that conditions favoring deposition of marine limestone or of fine detritus in extended areas are not favorable to the accumulation of coal beds.

MACROSCOPICAL STRUCTURE OF COAL IN BEDS.

The several benches of a coal bed may show marked differences aside from those already mentioned. The coal from one may be impure, containing large percentage of ash or sulphur; that from another may be hard, breaking into more or less regular blocks; that from a third may be brilliant, tender; that from a fourth may be prismatic, the rude prisms or columns being readily separable with the fingers; that from a fifth may be a solid coal, yet not hard enough to bear rough handling; while any one of the five benches may show saucer-shaped inclusions of cannel. These variations are shown in

⁶⁸ J. Phillips, "A Treatise on Geology," new ed., London, 1852, Vol. I., p. 190.

the Pittsburgh coal bed and are illustrative of those shown by nearly all beds. They are associated with equally marked chemical differences, which will be considered on a later page.

The coal in all benches has a laminated structure, due perhaps in some cases to pressure but in others to some other cause. The writer has traced laminæ, which tapered to nothing in each direction along an entry; whether or not this is characteristic, he cannot say. Any one who has attempted to determine this matter in a coal mine must have recognized that the intense application required should be devoted to something more important. H. D. Rogers concluded that in pursuing any brilliant layer, not more than one fourth of an inch thick, one may observe that its superficial extent is too great to permit the supposition that it had been derived from the flattened trunk or limb of any arborescent plant. It is certain, however, that pressure cannot account for the alternation of brilliant or glance laminæ with those of dull or matt coal, which one finds almost invariably. Usually these layers are very thin, but in many instances they are several inches thick. Sometimes this lamination seems to be due to the presence of mineral charcoal, which covers every surface obtained by splitting, but at others the charcoal is clearly without influence, for it lies in all directions. This mineral charcoal is a common constituent of all the fuels from anthracite to peat, but it is not an essential constituent, for layers of glance several inches thick have been found without it and Orton⁹⁴ has described a coal bed of workable thickness which shows no trace of it.

Fragments of plants, sometimes large, occur in coal. Occasionally they have been converted into fusain but more frequently they appear as glance coal,—though even these occasionally enclose more or less of the charcoal. Ordinarily they are flattened, the interior having disappeared while the cortex remained to be converted into glance. At times, they are merely impressions on the apparently structureless mass of coal, recalling the conditions observed in many peat deposits, where the great bulk of vegetable material has been changed into the flocky ulmic mass, while enclosed stems of trees,

⁹⁴E. Orton, "Mines of Muskingum and Licking Counties," Geol. Surv. Ohio, Vol. V., 1884, p. 881.

changing more slowly, are still recognizable. These stems are found in coals of all types and they are associated very commonly with leaves.

Lesquereux⁶⁵ asserted that *Stigmara* occurs as frequently in American as in European coals. In Greenup county of Kentucky, he saw a cannel, 4 feet thick, containing such abundance of *Flabellaria* and *Stigmara* that he believed the coal to be composed of those plants. In another, he found great numbers of *Stigmara* and beautiful impressions of *Lepidodendron*. Coal beds I. and XII. in western Kentucky are composed in places of flattened *Stigmara*, *Calamites* and *Sigillaria* with, in I., *Lepidodendron*. The Breckenridge deposit is rich in fine impressions. Long ago, E. B. Andrews, in writing of the Ohio and Kentucky cannels, said that *Stigmara* seemed to revel in the ooze which became cannel. Orton⁶⁶ says that the upper or bituminous portion of the Upper Mercer coal bed contains "the most beautiful specimens of *Stigmara*; nearly every mine car contains what would be a prize in a geological museum." These retain their lateral appendages. Many incidental, possibly accidental references are found in other geological reports, but they give no details. At the same time, they suffice to show that remains of trees are recognizable in the coal of very many beds and that *Stigmara* is not confined to the lower part of the deposit, but occurs in all portions in bituminous as well as in cannel.

Dawson⁶⁷ examined carefully every coal bed exposed in the long South Joggins section. Many deposits of inferior coal in Divisions 3 and 4 are composed of recognizable leaves and stems and there are beds of clean bright coal containing *Sigillaria*, *Cordaites* and other forms. The stems are almost invariably prostrate, but in one coal bed he saw a coaly stump and an irregular layer of mineral charcoal, "arising apparently from decay of similar stumps." In another bed, composed of prostrate *Sigillaria* with *Cordaites*, etc., he found a

⁶⁵ L. Lesquereux, "Geology of Pennsylvania," 1858, Vol. II., p. 841; Third Rep. Geol. Surv. Ky., 1857, pp. 529, 532, 548; Fourth Rep., *ibid.*, 1861, pp. 342, 349, 368, 379, 405, 412.

⁶⁶ E. Orton, Jr., Ohio Geol. Surv., Vol. V., 1884, p. 850.

⁶⁷ J. W. Dawson, "Acadian Geology," 2d ed., pp. 159, 162, 168, 171, 173, 174, 190, 438.

stump as mineral charcoal, while, in another, a trunk was seen, reduced to little more than coaly fragments, surrounded by a broken, partly crushed cylinder of bark. His study convinced him that the bark of *Sigillaria* and allied plants gave the bright coal, while wood and bast tissues yield mineral charcoal, the dull coal coming from herbaceous plants and mold.

Goeppert⁶⁸ found in the coal itself not only the plants which characterize the accompanying shale, but also many other species, especially of *Sigillaria*. The coal contains, in areas studied by him, *Stigmaria*, *Sigillaria*, *Caulopteris*, *Calamites* and other types forming stratified beds, 30 to 40 feet thick. Of the stems, only the rind remains and that is pressed flat. Where the chemical change was long continued, the features of the rind disappeared and the coal became structureless; but he often saw structureless coal pass into that with well-defined structure. At some localities the coal is composed of Araucarian stems and *Stigmaria*, while at others *Lepidodendron* is so abundant that one can hardly find a piece not containing that plant.

Grand'Eury⁶⁹ says that *Stigmaria* is very abundant in the coal of Rive-de-Gier; that *Cordaites* forms the greatest part of the coal in mines near Saint-Chaumont and in those of the Chazotte; it seems to be almost the only form in the coal of Tartaras, but is associated with ferns at Peron Midi and at Gandillon. At some places near Saint-Etienne, *Sigillaria* makes up practically whole beds of coal. Conditions are similar in other parts of Europe. He cites von Ettinghausen, who states that, at Radnitz, the coal-forming plants are *Sigillaria* and *Stigmaria*, with *Lepidodendron* and *Calamites*, but the latter two as well as the ferns are unimportant. Grand'Eury found similar conditions at Eschweiler, Wurm, Essen and Saarbrück; Geinitz called the Plauen deposit, *Calamites* coal. But Grand'Eury emphasizes the fact that a coal bed has not been formed by any single kind of plant. He remarks that occasional specimens of stems are found, converted into carbonized wood, showing the

⁶⁸ H. R. Goeppert, "Prize Essay," 1848, pp. 69, 70, 72-75, 276, 277, Pl., Fig. XVI.

⁶⁹ C. Grand'Eury, "Flore carbonifère du Département de la Loire et du Centre de la France," Paris, 1877, pp. 153, 168, 212, 213, 259, 396-398.

cortex and the intra-cortical fusain, which is finer than that from the wood.

Fayol⁷⁰ learned to distinguish coal made from *Calamodendron*, *Cordaites* or ferns as readily as he could distinguish a piece of beech from one of fir. He recognized these types first in isolated laminæ, but afterwards in brilliant laminæ occurring in the thickest and purest parts of the Grande Couche. He saw tree trunks in Commentry, some buried in the lower benches of the coal and others passing from the coal into the overlying shale. One fourth of one percent of the trees in the coal are vertical, an equal proportion are inclined and the others are prostrate. Few trunks in coal are cylindrical; where such stems occur, one can prove usually that one of the extremities is in sandstone.

David,⁷¹ in describing deposits of Kerosene shale, reports that in one mine at the end of Megalong ridge, the shale contains erect stems of *Vertebraria*; in another, prostrate stems; in a third are flattened stems or "barky casings of plants turned into bituminous coal, over four inches in width." David saw many vertical and prostrate stems of *Vertebraria* in the Shale at a locality in Cook county. Wilkinson saw at Joadja creek impressions of *Vertebraria* lying horizontally in the Kerosene shale as well as numerous vertical stems of the same plant, whose lustrous, bright substance is in striking contrast to the dull luster of the enclosing shale. Nathorst found stems of *Bothrodendron* in the Devonian coal of Bear island and stems are present in many brown coal deposits as well as in the peats of modern bogs.

FOREIGN BODIES IN COAL.

The presence of tree stems in coal is normal; but the coal often contains what may be regarded as foreign bodies.

Nodules of calcareous clay-iron stone are familiar objects in coal beds as well as in the Coal Measures shales. They are from mere specks to balls a foot or more in diameter. Occasionally they

⁷⁰ H. Fayol, "Études," etc., pp. 135, 196, 198, 206, 207.

⁷¹ T. W. E. David, Dept. Mines New South Wales, Rep. for 1890, 221-224; C. S. Wilkinson, *ibid.*, p. 208.

are rudely spherical but for the most part the shale is irregularly oval and occasionally even plate-like. When enclosed in coal beds, the laminæ are displaced about them as though the final compression had taken place after formation of the nodule; and this feature is as characteristic of coals which have not been distorted as of those which have been folded. The nodules are often fossiliferous, containing marine shells at times but land forms and plants at others—as those obtained at Mazon creek in Illinois, in which are remains of many animals as well as plants, all marvelously well preserved. Such nodules have been found in the Devonian, for Nathorst⁷² obtained some from shales of that age in Spitzbergen; *Lepidodendron* and apparently *Bothrodendron* were recognized in several of them, while others contain remains of fishes.

More than 80 years ago, calcareous nodules more or less ferruginous, occurring in the roof and coal of a thin bed in the Lancashire coal field, attracted Binney's attention and were made the subject of a memoir by Hooker and Binney. Since that time, such nodules have been discovered in many lands and have been investigated by students in Europe. In this summary, reference is made only to some of the later publications.⁷³

Coal balls were supposed for a long time to be confined, in England, to a single horizon, the thin Lancashire coal bed known as the Mountain Upper Foot. This, in the Lower Coal Measures, is at a variable distance above the Ganister coal bed, one of the most per-

⁷² A. G. Nathorst, "Zur palæozoischen Flora der arktischen Zone," *Hand. K. Svens. Vetén-Akad.*, Band 26, No. 4, 1904, pp. 11, 13.

⁷³ D. Stur, "Ueber die in Flötzen reiner Steinkohle enthaltenen Stein-Rundmassen und Torf-Sphaerosiderite," *Jahrb. d. k. k. Geol. Reichsanst.*, Vol. XXXV., 1885, pp. 628 et seq.; A. Strahan, "On the Passage of a Seam of Coal Into a Seam of Dolomite," *Quart. Journ. Geol. Soc.*, Vol. LVII., 1901, pp. 297-304; H. B. Stocks, "On the Origin of Certain Concretions in the Lower Coal Measures," *ibid.*, Vol. LVIII., 1902, pp. 46-58; M. C. Stopes and D. M. S. Watson, "On the Present Distribution and Origin of the Calcareous Concretions in Coal Seams, known as 'Coal Balls,'" *Phil. Trans. Roy. Soc.*, Ser. B, Vol. 200, 1908, pp. 167-208; W. Gothan und O. Hörich, "Ueber Analoga der Torfdolomite (Coal Balls) des Carbons in der rheinische Braunkohle," *Jahrb. k. preuss. Landesanst.*, Band XXXI., Teil II., 1910, pp. 38-44; C. Barrois, "Étude des strates marines du terrain houiller du Nord," 1^{re} Partie, 1912, pp. 4, 9, 38, 62.

sistent members of the column. The Ganister, when separated by several yards from the upper Foot, contains no balls; but when the parting is only a few inches, the balls are in both beds. There is no regularity in the distribution. The Hard coal bed, near Halifax in Yorkshire and belonging apparently at the same horizon, also contains similar balls. These concretions have a slickensided surface and the coal laminæ curve around them; occasionally a faulted specimen is found. In size they vary from an inch to a foot or even more—one, near Shore, weighs 2 tons and replaces the coal from roof to floor. These balls in the coal contain plant remains in condition of remarkable preservation.

The roof shale of this coal bed carries abundant remains of marine animals along with much fragmentary plant material. "Bullions," "baumpots" or "Goniatite nodules" occur in this shale and are as characteristic of it as the coal balls are of the coal. These roof balls enclose shells with which there are often bits of plants, rarely well preserved but at times admitting of generic determination. Sphaerosiderites, answering to the English roof balls or bullions, have been found within the Nord (France) basin in marine shales, sometimes resting on thin coals. They, like the English balls, contain *Goniatites*, *Productus* and other forms; but Barrois does not note the presence of similar concretions in the coal.

Sphaerosiderites were obtained at collieries in the Ostrau coal field from the roof shale of the Heinrichs and Coaks coal beds; in each case the shale is marine. The balls from the higher shale are occasionally fossiliferous but those from the roof of the lower bed seem to be without fossils. The lower part of this shale, however, is crowded with small balls of pyrite, many of which are fossiliferous, while many shells in this portion have been replaced with pyrite. The balls, for the most part, are small, very irregular in form and often are polished, so that they might easily be mistaken for erratics. Sometimes several are united but ordinarily they are separate and are scattered throughout the shale. They are encrusted with powdery matter, one to two millimeters thick, which is removed readily by washing. When exposed to the weather, their concretionary structure soon becomes apparent.

The Coaks bed contains great numbers of coal balls or plant-sphaerosiderites; Stur obtained several hundreds in a large block of coal shipped to him from the mine. These are especially abundant in the upper bench and on the west side of the area, where the roof balls also are most numerous. The remains of plants in the coal balls are always well-preserved but those in the roof balls are in bad condition.

The roof balls, according to Stopes and Watson, have from 4 to 6 per cent. of clay, whereas the coal balls have often no more than a trace. Stur has given two analyses of those from the roof, which are quite dissimilar:

Carbonate of calcium	61.43	29.01
Carbonate of magnesium	2.86	4.33
Carbonate of iron	16.13	25.09
Carbonate of manganese	1.73	—
Sulphide of iron	—	6.45
Clay	2.49	2.22
Insoluble matter	13.03	30.20
Water and loss	2.33	2.70

The coal balls show extreme variations in some constituents. According to Stopes and Watson, those from Bacup are chiefly dolomite; whereas several of those from Shore show very little magnesia, and only 2 of the 5 specimens analyzed have more than 5 per cent. of carbonate of magnesia. Stocks analyzed two from Yorkshire localities, which gave

Carbonate of calcium	64	82
Carbonate of magnesium	2	0.75
Sulphide of iron	21	12

with small per cent. of sulphate of calcium, silica, clay and organic matter. Sometimes the nodules contain pieces of fossilized wood which are large enough for study. They also show much variation, 4 specimens giving

Carbonate of calcium	86	24	87	49
Carbonate of magnesium	4	2	3	6
Sulphate of calcium		14	1	9
Sulphide of iron		49	5	24

with other constituents in small proportion; the fossilized wood like the mass of the concretion is composed chiefly of carbonate of calcium and sulphide of iron. The analysis of Stur's specimen differs somewhat; it is

Carbonate of calcium	56.52
Carbonate of magnesium	10.02
Carbonate of iron	15.60
Clay	0.89
Insoluble matter	0.17
Organic matter, water, loss	16.80

but, like the other analyses, it shows the great freedom from clay and silica, which are so important in roof balls. This difference led Stur to distinguish the latter as clay-sphaerosiderites.

Except at the Bacup locality, dolomite is not the important constituent of the coal ball. Strahan's notes respecting the Wiral colliery in Cheshire seem to have some bearing on this matter. The coal there was 4 feet thick and of good quality where opened; but within a short distance bands of stone, 1 to 10 inches thick, appeared, some of them consisting of spherical pellets. Within 250 yards, the coal was replaced with this rock, but the roof and floor remained unchanged, save that the former had become reddened—this change, however, being unrelated apparently to that in the coal. The rock is black and hard, but weathers gray; the structure is pisolitic and the concretions are sometimes united, at others independent and separated by coaly matter. They consist of dolomite with some coaly material, iron, silica and clay. Some fragments are composed of small masses or irregular crystalline layers, separated by fine mud containing quartz and flakes of mica; while others, consisting partly of woody tissue filled with dolomite, may be regarded as wood fragments, impregnated with and cemented by dolomite. When this dolomite has been removed by acid, a copious residue of carbonized fibers is obtained.

These balls or sphaerosiderites are concretions formed in the coal and shale after the deposits had been made but before consolidation. The laminæ of coal and shale curve around them and some of the concretions were broken during the later compression.

Green⁷⁴ in describing the Yorkshire roof balls says that the *Goniatites*, *Aviculopecten* and other shells enclosed are not flattened as are those in the shales. The plant material in the coal balls is in wholly uncompressed condition, so that the minutest details of structure can be recognized—as one may see by consulting Williamson's memoirs in the *Transactions of the Royal Society*. Stur found the stems of plants not only uncompressed but also, in some cases, not wholly decayed, so that the concretions were formed before the chemical change had been completed. Stopes and Watson were convinced that they had traced a stem continuously from one coal ball into another; Wild says that the Lancashire "bullions," composed of fossil wood, occasionally show rootlets working their way through the decaying wood, separating the fibers which now surround them. But vegetable fragments in roof balls are different; as Stur remarks, they are coaled and evidently much changed; they tell little of relations and less of structure.

But coal balls are not confined to the Coal Measures. Gothan having noted that the localities, where the balls had been obtained, were all within paralic basins set himself to discover them under other conditions. Petrified stems are common in Tertiary beds, where, as deposition centers in brown coal, they have given opportunity for concentration. Such silicified or at times pyritized stems occur frequently in the Halle brown coal and in the Rhenish brown coal one finds the well-known oolite wood. But these are not wholly analogous to coal balls, which are bits of petrified peat, penetrated at times by roots of vegetation growing above. In searching the survey collections at Berlin, Gothan found a piece of brown coal from the Donatus mine near Cologne, which contained spherules of carbonate of iron, the same as the material of the oolite wood. Deposition had not been confined to the wood but had reached into the actual peat. Specimens were procured from Flügel, who had mapped the area, and they proved to be part of the bed, replaced with material like that of the plant-balls described by Stur. Gothan suggests the name of Torf-Dolomite. Microscopic examination by Hörich showed the close resemblance between these forms and the coal balls. As a

⁷⁴ A. H. Green, "The Geology of the Yorkshire Coal Field," p. 108.

rule, however, the plant remains are less well preserved than in the coal balls; they are so disintegrated that in many cases they are not identifiable. Roots are best preserved, probably because they entered when the surrounding mass had already become peat. They show no trace whatever of compression. Some fragments of stems have great lacunæ, indicating that they are of plants belonging to a moist habitat. The great variety in the plants suggests that the deposit is a typical Waldtorf, which accords with the belief that the brown coals were deposited as Waldmoors.

This conclusion is very similar to that reached by Stopes and Watson, who recognize a swamp vegetation in the coal balls, as, indeed, Stur had done long before. Stur had noted the difference in condition of the vegetable material in the two types of balls, and this difference is emphasized by Stopes and Watson. Scott had observed that the roof-ball flora, though of Lower Coal Measures age, has no slight resemblance to that of the Permian, and those authors think that it is comparable to an upland flora, so that it may be more characteristic of the widespread vegetation than is that of the coal balls.

Dolomite, calcite and carbonate of iron are not the only minerals replacing plant material in concretionary fashion. E. B. Andrews and Lesquereux found wood in coal wholly replaced with sulphide of iron, the form being uncompressed; but no microscopic study was made to ascertain whether or not any trace of structure remained. The Grand'Croix flints are of the same type as the coal balls and they yielded interesting results to Renault, who recognized that they are petrified peat. Near Salem in Oregon there are fossil stems, which show all gradations between lignite and silica within a few feet.

The source of the material forming the balls has been subject for speculation. Balls from the more celebrated localities are in coal beds with marine deposits as the roof. Binney thought the shells provided the material, but objection was made that the shells are not dolomite and that one should look to sea-water as the source. As the roof shales in the Coal Measures localities are marine, sea-water must have covered them all alike; yet in Lancashire, the balls are dolomite at Bacup, whereas at Shore only one specimen showed

as much dolomite as calcite while in three others dolomite is absent or insignificant. Dolomite is unimportant in the Yorkshire balls, but it is in large proportion in Stur's specimen, while it is shown in small proportion by the roof balls of the same area. It would appear that sea-water can hardly be regarded as the source, in view of the marked variations found within short distances. And this suggestion is strengthened by the fact that Gothan's Torf-dolomite closely resembles in composition the coal balls described by Stur.

It may be preferable to seek the source in the materials themselves, the inorganic matter forming the shales and the ash of the coals. Carbonate of magnesium is found in most of the coals as well as in peats and it is often an important constituent of wood ash. The varying proportion in the balls may indicate merely a varying proportion in the shales, depending on the nature of the rock whence they were derived. And this seems to be reasonable, when one considers the composition of limestones. McCreath⁷⁵ made many analyses for the Pennsylvania survey, which illustrate the conditions. The Vanport limestone of the Allegheny formation is of marine origin throughout and is one of the widely extended deposits. Carbonate of magnesium rarely exceeds 2 per cent. and very often is less than 1 per cent.; but on the northern border, where it extends into old valleys and is mingled with land material, the percentage increases, attaining 6.65 at one locality. A similar change appears in the Ames limestone. In Harrison county of West Virginia, that limestone is approaching its southern limit as a marine deposit. It contains in its upper division 25 per cent. of alumina and in the lower, 18 per cent. of silica. The influx of land material is very marked, though the marine fossils persist in great numbers; the carbonate of calcium varies from 40 to 48 per cent. and carbonate of magnesium from 15 to 21 per cent.⁷⁶ McCreath's analyses of Monongahela and other limestones, which from their relations must be regarded as non-marine, show that in some cases they are markedly dolomitic and with few exceptions they have a

⁷⁵ A. S. McCreath, Sec. Geol. Surv. Penn., Rep. *MM*, 1879, pp. 281-362; Rep. *M3*, 1881, pp. 79-94.

⁷⁶ B. W. Hite, in West Va. Geol. Surv., County Reps., 1912, p. 251.

large percentage of insoluble residue. Lesley's⁷⁷ study of the elaborate series of analyses, showing composition of the 115 layers of limestone exposed opposite Harrisburg, led him to conclude that in this exposure two types of deposits alternate; one is of limestone, with 2 to 3 per cent. of carbonate of magnesium and 1 to 2 per cent. of insoluble matter; the other, a dolomitic limestone, with 26 to 35 per cent. of carbonate of magnesium and the insoluble matter is from 7 to 15 per cent. The large percentage of silicate of aluminum is always in the dolomitic beds. The layers analyzed are from a few inches to 8 feet thick, are distinctly separate and the extreme variations of composition are often in direct contact. One who reads carefully the whole of Lesley's discussion is compelled to recognize that the differences are original, not secondary, that they are due to conditions in the drainage area, not to change in composition of the water in which they were deposited.

The replacement described by Strahan may be due to mineral springs as are the flints of Grand'Croix.

Remains of animals may be regarded as foreign bodies. Cannel often contains abundance of such remains. In such localities, on both sides of the Atlantic, it has been a rich mine for the palæontologist. Marine shells have been found in ordinary coal. The Harlem coal bed, underlying the Ames limestone, has marine forms in its topmost layer at a locality in Ohio as well as at one in West Virginia and Raymond found a marine shell in the Kittanning coal at a locality in Ohio. Remains of higher animals occur in coals of later age. Anker⁷⁸ examined a brown coal of Molasse age in Styria, which so closely resembles black coal that is distinguishable only by its geological position and its occasional woody structure. Bones are present in 3 layers, where they are very numerous, though fragmentary. A jawbone, retaining the teeth, was recognized as belonging to *Hyena*. Bones of mammals occur frequently in modern swamps.

⁷⁷ J. P. Lesley, Rep. *MM*, pp. 360, 361.

⁷⁸ Anker, "The Occurrence of Bones of Animals in a Coal Mine in Styria," *Proc. Geol. Soc. London*, Vol. I., 1834, p. 467.

Fragments of rock are the foreign bodies which are the most perplexing. The earliest recorded observation seems to be that by Phillips in 1865, followed by that of Noeggerath in 1862, both of which have been cited by Stur. Roemer⁷⁹ soon afterward described 3 small fragments from a coal bed in Upper Silesia; they were of crystalline rock, unlike anything known in Silesia. E. B. Andrews in 1870 announced the discovery of a waterworn quartzite fragment in the coal at Zaleski, Ohio, half embedded in the coal. Newberry in 1874 saw a fragment of talcose slate in the parting of Coal No. 1 at Mineral Ridge, Ohio, which he thought might have come from the Canadian Highlands; somewhat later he found a rounded quartzite fragment in the Block coal, resembling a Huronian rock in Canada. Stevenson in 1877 reported the discovery of a waterworn limestone boulder embedded in the Sewickley coal of Fayette county, Pennsylvania. It was about 2 feet in diameter and extended above as well as below the coal. He believed that it had not been deposited prior to the coal, for that was splashed as though the fragment had fallen into soft material. Similar notices appeared from time to time but in all cases they were merely casual.

Stur⁸⁰ in 1885 gave a summary statement of knowledge respecting such occurrences. He notes the discovery by Roemer in 1883 of a mass weighing 55 kilogrammes, granite such as is unknown in the region. He adds instances coming under his own observation in several Austrian coal fields, but the notes refer to somewhat widely separated localities and the fragments are of small size. Radcliffe⁸¹ described 6 bowlders from Dukenfield, England, embedded partly in the coal and partly in the overlying shale. The portion within the coal had a coaly crust but no such crust appears on the part within the shale. All are of quartzite and the weight was 5 to 166 pounds. One specimen was on edge. W. B. Dawkins

⁷⁹F. Roemer, "Ueber das Vorkommen von Gneiss- und Granulit-Geschieben in einem Steinkohlenflotze oberschlesiens," *Zeitsch. Deutsch. Geol. Gesell.*, Band XVI., 1864, pp. 615-617.

⁸⁰D. Stur, "Ueber die in Flötzen reiner Steinkohle enthaltenen Stein-Rundmassen," etc., pp. 613-647.

⁸¹J. Radcliffe, "On Grooves and Quartzite Boulders in the Roger Mine of Dukenfield," *Quart. Journ. Geol. Soc.*, Vol. XLIII., 1887, pp. 601, 603, 604.

remarked in the discussion that such fragments occur frequently in Lancashire and that all are of quartzite; Bonney made the broader statement that they are of common occurrence in coal. In the same volume, J. Spencer referred to a granite fragment, weighing 6 pounds, which had been found in the Ganister coal bed and he adds that the surrounding coal was undisturbed. He remarked that bowlders had been found at many localities, that they were always isolated and that they had come from a distance. Gresley in 1890 reported that a well-rounded quartzite boulder, 11 by 8 inches, had been taken from underclay at 1 foot below the Mammoth coal bed near Mr. Carmel, Pennsylvania.

Orton⁸² says that prior to 1892 the Ohio bowlders had come from the Middle Kittanning coal bed at Zaleski. The first was discovered by Andrews in 1870, but many were discovered afterwards, there being at times scores in a single room. The largest weighs 400 pounds and is in the State museum at Columbus. A new horizon was made by finding a quartz boulder, weighing 10 pounds and 10 ounces, at Mineral Ridge. It was in undisturbed coal at 2 feet below the roof and it was covered with a closely adhering, slicken-sided crust of coal. Stainier⁸³ gathered observations made by himself and others in the Belgian fields. Some of the fragments are rounded and smooth, evidently rolled pebbles, while others are irregular in form like concretions, but composed of sedimentary material and so are to be regarded as foreign bodies. Pebbles of the former type were obtained at 8 localities. They are not rare in La Rochelle colliery of Charleroi at the 500-meter level but they are wanting at the 250-meter level. The bed yields an impure coal and earthy partings are numerous where the pebbles occur. The largest is oval, 14 by 8 by 8 centimeters. Schmitz obtained rounded fragments from localities in the Charleroi and Centre basins, and Lohest found them in the Liège basin. The largest specimens weigh 20 and 25 kilogrammes. It is noteworthy that the Belgian fragments are

⁸² E. Orton, "On the Occurrence of a Quartz Bowlder in the Sharon Coal of Northeastern Ohio," *Amer. Journ. Sci.*, III., Vol. XLIV., 1892, p. 62.

⁸³ X. Stainier, "On the Pebbles Found in Belgian Coal Seams," *Trans. Manchester Geol. Soc.*, Vol. XXIV., 1896, pp. 1-19.

of sedimentary origin; some resemble Carboniferous rocks and all are in coaly material. These records seem to suggest that pebbles are not abundant in coal and that they are even of comparatively rare occurrence—the instances noted by Orton and Stainier are not exceptions, as they are examples of extreme localization.

Barrois⁸⁴ undertook systematic study of the matter in a definite area and presented the results in an elaborate memoir, of which only the merest synopsis can be given here. Most of the fragments were obtained during a four months' exploration of the Vein-du-Nord, a double bed, showing great constancy in the explored area, which is 7 kilometers long. The upper bench, 0.25 meter thick, has 14 per cent. of volatile and only 2 per cent. of ash, while the lower bench, 0.35 meter thick, has 17.2 per cent. of volatile and 10 per cent. of ash. The rock fragments are coated with soft sooty coal, often pyritous, and the lamination is more or less distorted about them. In all, 295 specimens were secured, of which 86 per cent. were derived from Coal Measures rocks, a few from Cambro-Silurian deposits and nearly 11 per cent. from the distant Archæan. The largest fragment weighs about 120 kilogrammes or approximately 280 pounds. The great preponderance of fragments from the Coal Measures shows that outcrops of those rocks were not far away, so that at the time of the Assise d'Andenne—the Lower Coal Measures—the beds of that epoch were no longer mere muds and sands, but consolidated shales and sandstones; some fragments show even the jointing of contraction. Many are thoroughly water-worn, others are angular, and both types are mingled indiscriminately. In some other coal beds of this region, fragments have been found in the mur, coated with clay which is marked with lacework of *Stigmara* rootlets.

Fragments were found in all portions of the bed, from bottom to top, but the upper bench yielded 50 times as many as the lower. The number averages only one to each 100 square meters of area, but the distribution is irregular and they occur, as it were, in nests. The more abundant occurrences are associated with contractions of

⁸⁴ C. Barrois, "Étude de galets trouvés dans le charbon d'Aniche, Nord," *Ann. Soc. Géol. du Nord*, Vol. XXXVI., 1907, pp. 248-330.

the bed, where the roof or the underclay replaces more or less of the coal. Rolls in the roof usually consist of material differing in character and arrangement from the overlying shale, as though deposited in channels of streamlets made after formation of the coal. The underclay swellings may have been laid down in drowned channels made anterior to formation of the coal and occupied after that formation had been begun. Variation in direction of channels during accumulation of the beds might account for distribution of the fragments but the existence of such waterways within this area is problematical and it is well to seek another explanation.

Phillips's hypothesis that the fragments were transported by trees, uprooted from banks of streams, has found favor with allochthonists and autochthonists alike; but there are serious objections to it. The weight of some fragments, upwards of 100 kilogrammes, is too great to admit of transportation by *Stigmaria*, while the presence of blocks of mud would suggest that hollow trees had shared in the work. In any event, there would always remain the remarkable purity of the coal, so difficult to explain in view of the great amount of inorganic material known to be transported by floating trees. There seem to be insuperable difficulties in the way of a conception that the presence of fragments is due to the agency of trees growing outside of the area in which coal was forming. Objection to the hypothesis of transport by floating ice is equally serious. Beyond doubt there were widespread changes in climatic conditions toward the close of the Palæozoic, but attempts to reconcile the tropical character of the Nord-basin flora with a cold climate have not been successful. The markings on the fragments do not resemble those made by glacial action.

The presence of fragments in the mur is proof that they were brought in prior to formation of the coal, when streams were distributing the detritus which became the mur. *Stigmariæ* became rooted in that and enlaced the fragments, which some day they were to transfer to the coal. The fall of trees, overturned in the marsh by age or wind, tore portions of the mur from below; fragments, there encased, came gradually to the surface of the coal; at times a stump fell into a stream and its load would be deposited in the

channel. This hypothesis explains local abundance of fragments by two factors; their previous existence in the mur and the fragility of the mur itself; so that they would form in succession part of the mur and part of the coal. The purity of the coal eliminates, during formation of the bed, the agency of convoys of allochthonous trees loaded with extraneous debris.

The condition is not peculiar to the Coal Measures. It is found in coal formations of other ages. Hutton⁸⁵ found in the Upper Cretaceous of southern New Zealand a sandstone mass, 8 feet by 3, resting on the coal, which convinced him "that there can be no doubt that this boulder has been floated to its present position among the roots of a tree and that therefore the coal beds are formed partly from driftwood." He states the Tertiary brown coals in several fields contain pebbles of white quartz; these beds, according to Hector, rest on fireclay. Jack⁸⁶ found pebbles in coals of Upper Cretaceous age in Queensland.

The presence of rock fragments in coal has always been perplexing to allochthonists and autochthonists alike, though each seems to be certain that in some way or another they afford an important argument in favor of his doctrine. They are certainly transported materials; some were brought from rocks far away and most of them are distinctly waterworn. If all were small, any geologist could conceive of an explanation, which would be satisfactory to himself, as refutation might be difficult; but when one has to deal with masses of several hundred pounds, such as the Ohio blocks, transported several hundreds of miles, the problem becomes serious.

Some writers have been inclined to regard ice as the transporting agent; but the character of the Coal Measures vegetation appears to be conclusive against the supposition that intense cold prevailed during any part of the year at any locality whence the fragments have been reported. It is very true that sharply contrasted climates may exist only a few miles apart, as in southern California, but that

⁸⁵ F. Hutton, "Report on Geology and Gold Fields of Otago," Dunedin, 1875, pp. 101, 103.

⁸⁶ R. L. Jack, "Geology and Palæontology of Queensland and New Guinea," London, 1892, pp. 536, 538.

condition requires topographical features which did not exist. The whole Coal Measures area of Ohio was a low plain; the nearest highlands were in Canada, hundreds of miles toward the north, and the Appalachians, hundreds of miles away toward the east. The agency of ice must be set aside as in the highest degree improbable.

The majority of authors have supposed that uprooted trees floated away carrying the masses entangled in their roots; but the difficulties involved in this conception appear to be insuperable. There can be no doubt that trees do seize such blocks and that under proper conditions they could transport them. Any one, who has seen the manner in which the white birch of the White Mountains enwraps its roots about blocks of stone weighing half a ton or more, recognizes that trees do seize large fragments. But that is not the question. The observer is confronted at once with the problem of conveying that tree and its load to deep water, sea or lake, where the great tree, 75 or more feet high, may float in vertical position, almost wholly submerged. Trees grow on the land, where alone the fragments can be obtained. The transfer cannot be made by torrents, as tree and load would be deposited at the first rapids. A débâcle, like that of Martigny or Johnstown, cannot be conceived of as the agent, since a topography would be required such as did not exist near any of the extensive coal fields whence large fragments have been reported. Even had it existed, the terrific collisions, as the flood dashed through narrow gorges and spread out in wider portions of the valley, would have dislodged the fragments long before reaching the open water. The boulders cannot be relics of floating islands, such as those of the Orinoco, Amazon or Congo, since the origin of those islands forbids the suggestion.⁸⁷ Nor is there any reason to suppose that trees growing on the seashore could become the transporting agents, for, even though river-worn or wave-worn fragments were abundant on the shore, the difficulty of transferring the tree to deep water would still remain. If the trees grew on the river banks, along the lower reaches of a great stream, and were undercut, they would be stranded at the first bar to become

⁸⁷ "Formation of Coal Beds," these PROCEEDINGS, Vol. L., 1911, pp. 551, 553, 554.

snags or towheads, which even the greatest flood possible on such a river could not dislodge, as conditions along the Mississippi abundantly show. It is impossible to conceive of any means whereby a tree capable of carrying such a load could be floated away to deep water, unless it grew on the wall of a fiord—where it could not secure the water-worn fragments.

The assumption that shales, sandstones and conglomerates were deposited necessarily in deep water or in a permanent body of water must be regarded as unsupported by any positive evidence. The writer, during a tedious search through the literature, has not found that authors think that the proposition needs evidence; it seems to be accepted as axiomatic. But evidence to refute the doctrine abounds in the Tertiary and Quaternary and, in so far as the Appalachian Coal Measures are concerned, the facts seem to indicate that they are flood-plain deposits and reworked alluvial fans. This condition may afford a clue to explanation for some of the occurrences. Rivers, torrential in their upper reaches, flowed across the plain. Rolled fragments of varying size were pushed along the beds. Pebbles of quartz,⁸⁸ 5 inches in diameter, have been found in the Sharon of southern Ohio at not less than 300 miles from their source. During a great flood, if the stream were dammed temporarily, the water would sweep over the "bottoms" or break across the necks of curves; a new channel would be cut, the old channel above for a short distance would be scoured and its sand and pebbles would be strewn on the river-plain. This happens only too often along the Mississippi, as has been shown on preceding pages. In such a rush of water, a block of 400 pounds would be gathered up in the mass as readily as though it were a pebble; but gravity would act promptly and the coarse fragments in the load would be left scattered on the surface while the finer materials would go far beyond. Succeeding floods would cover the sands and gravels as well as the larger fragments with finer materials in which the larger river-worn masses would be widely separated, for the most part, though here and there they would be grouped in smaller areas. One finds this

⁸⁸ E. B. Andrews, Ann. Rep. Geol. Surv. Ohio, 1870, p. 67.

condition in the "bottoms" of large and small streams alike. The fragments in the underclay, mentioned by Barrois, Ashley and Gresley, were not deposited with the clay but before it; their distribution is wholly similar to what is seen now. The mode of transference to the coal, as described by Barrois, is in accord with what one may see in actual bogs; once transferred by plants rooted in the underclay, they would be removed successively into higher portions by plants rooted in the bog—for there is every reason to believe that the Coal Measures plants had as much liking for peat soil as is shown by many towering plants of the present day.

At the same time, the writer recognizes that the suggested explanation is not altogether satisfactory at some localities, where the required conditions cannot be proved.

MICROSCOPIC FEATURES OF COAL.

The unaided eye can discern many features of coal in the bed; it can group types into glance, matt, cannel, fusain; at times, it can find relations between a certain type of coal and the plants which produced it, so gaining insight into possibly contrasted origin of glance and matt coals; it can recognize great difference of physical features in the several benches of a coal bed, which lead to conviction that each bench may have had its own peculiar history, may have been formed under its own peculiar conditions, very different from those of the other benches. But one quickly discovers that intimate structure of coal can be ascertained only by aid of the microscope, since to the unaided eye, the great mass of coal is wholly structureless.

Nicol and Witham appear to be the first to apply this method of investigation, which Witham utilized especially in studying the structure of fossil plants. Hutton was the first who made a study of the coal itself. In a slice of coal, prepared by Witham, Hutton⁶⁹ observed some remarkable cells within the portions which showed no vegetable structure. He made sections of the coals mined at New-

⁶⁹ W. Hutton, "Observations on Coal," *Proc. Geol. Soc. London*, Vol. I., 1834, pp. 415-417; also in *Lond. and Edinb. Phil. Mag.*, Vol. II., 1833, pp. 302-304.

castle. These are, 1, Rich caking coal, which is the most abundant and the best in quality; 2, Cannel or Parrott or Splint; 3, Slate coal, consisting of the others in alternating layers so as to give a slaty structure. Vegetable structures can be recognized in all; but besides this, all show cells filled with wine-colored material, so volatile that it can be expelled by heat before any change takes place in the other constituents. The caking coal contains very few and those are elongated; he supposed that originally they were circular and that the changed form was due to pressure. The finest portions of the coal, in which "crystalline" structure is best developed, show no cells; the crystalline structure indicates a more nearly perfect union of the constituents, a more nearly complete destruction of the original plant texture. The Slate coal contains two kinds of cells, both filled with bituminous material; one kind is that seen in the caking coal, but the other is in groups of smaller cells, elongate circular in form. The first type occurs rarely in cannels and related coals, where the whole surface of the section is covered with an almost uniform series of cells of the second type, filled with the bituminous matter and separated by thin fibrous divisions. He was led by these features to believe that difference in coals is due to difference in the original plants. Another type of cells, empty, seem to have contained gas. It is clear that Hutton recognized a structureless portion of the coal containing plant fragments, of which the texture is still recognizable. He made no effort to explain the origin of the bituminous material.

Link⁹⁰ found vegetable structures in all coals and recognized that coal is made up of woody matter, usually much comminuted; but in some the structure is loose like that of modern peats, while others are dense like some denser peats of modern origin. Bailey in 1846 and Goeppert in 1848 described vegetable structures in coal. Dawson's⁹¹ first important publication bearing upon the subject was in 1846 but his studies were continued for many years thereafter.

⁹⁰ H. Link, "Ueber den Ursprung der Steinkohlen und Braunkohlen nach mikroskopischen Untersuchungen," *Abh. k. Akad. Wiss.*, 1838, pp. 33-44.

⁹¹ J. W. Dawson, "Notices of some Fossils found in the Coal Formation of Nova Scotia," *Quart. Journ. Geol. Soc.*, Vol. III, 1846, pp. 132-136; "Acadian Geology," 2d ed., 1878, pp. 393.

He rejected the use of prepared sections and resorted to the chemical treatment employed by Goeppert. The coal was broken up and the vegetable tissues were separated so as to exhibit their characteristics. He selected for study only specimens which in each case consisted of a single plant, so that he was enabled not only to ascertain the structural features of many forms but also to determine in great measure the share which each type of tissue had in making the coal. Reinsch, in 1881, utilizing prepared sections, elaborated Hutton's work and discovered great numbers of what he took to be very humble forms of vegetation.

Grand'Eury⁹² laid emphasis on the vast proportion of amorphous material, the vegetable jelly, which holds the still recognizable plant remains. Clearly, much of the vegetable material was transformed into a kind of pulp, which forms a large part of the coal. "The great number of organs preserved in the form of teguments gives an idea of the quantity of vegetable jelly, which one finds to have formed the coal, in proportion to the epidermis material which is contained there." This jelly was not always so fluid or so homogeneous as to destroy all traces of vegetation for those are still recognizable. In the following year, von Gümbel⁹³ published the results of his elaborate studies of the fossil fuels from peat to anthracite. Throughout the whole series he recognized the amorphous material, Carbohumins, clearly the vegetable jelly of Grand'Eury, the pulp of H. D. Rogers. He employed chemical processes to disintegrate the coals and to lay bare the vegetable structures, remaining in the enclosed fragments. He was enabled to show that while the glance coal consists of different kinds of vegetable matters, the predominating substance is the parenchymatous cells of the rind, along with tissue like wood, parts of leaves, epidermis flakes, separated disks and spore-like bodies, the whole enclosed in amorphous material. It is probable that the plant remains have been converted so thoroughly into homogeneous coal that determination of any vegetable

⁹² C. Grand'Eury, "Memoire sur la transformation de la houille," *Ann. des Mines*, VIII., Vol. I., 1882, p. 109.

⁹³ C. W. von Gümbel, "Beiträge zur Kenntniss der Texturverhältnisse der Mineralkohlen," 1883.

structure is very difficult. The matt coal consists mostly of prosenchymatous cells, which von Gümbel thinks derived from parts of leaves; much epidermis material is present along with spore-like bodies and broken fibrous coal. His conclusions in respect to these matters are like those reached by Dawson. Von Gümbel proved definitively the intimate resemblance of cannel, boghead and other forms to each other and to the Lebertorf of East Prussia. He recognized algæ-like forms along with spores in bogheads and cannels, thus anticipating much which has been published in later years. His figures illustrate well the characteristic forms, but evidently he had doubts respecting the relations, as he refrained from applying names to the forms.

Morris, Wethered and others early recognized spores in coal and some were inclined to attribute to these a very important share in the accumulation of coal beds. They seem to be in all coals. Nathorst⁹⁴ found macrospores very abundant in the great coal of the Devonian on Bear Island, south from Spitzbergen. Wethered and some others were regarded by Newberry and by Dawson as placing too much stress on the contributions by spores; while recognizing that spores are almost always present, and at times even in large numbers, they thought that these hardly deserve consideration as important constituents of coal. Kidston⁹⁵ has presented the matter in a simple way, which seems to meet requirements. He says that the quantity of spores from the lycopods was unquestionably enormous, and that they entered largely into the formation of some coals. There are bands composed wholly of megaspores and of microspores, varying in thickness from a mere membrane to a centimeter or more. In coal broken transversely, they give a zoned appearance, the bands of spores being distinguished by their dull color within the brilliant coal.

Van Tieghem,⁹⁶ in studying sections of flint concretions prepared

⁹⁴ A. G. Nathorst, "Zur der devonischen Flora der Bären Insel," *Handl. K. Svens. Vet. Akad.*, B. 36, No. 3, 1902, pp. 40-43.

⁹⁵ R. Kidston, "Les végétaux houillers recueillis dans le Hainaut belge," *Mem. Mus. Roy. d'Hist. Nat. de Belgique*, Tome.IV., 1911, p. 208.

⁹⁶ Ph. van Tieghem, "Sur le ferment butyrique (*Bacillus amylobacter*) a l'époque de la houille," *C. R.*, Vol. 89, 1879, p. 1102.

by Renault, made the capital discovery that bacilli existed in Coal Measures time. Renault elaborated this observation afterwards in some memoirs which are captivating in style. The studies of bog-heads and related types by C. E. Bertrand and Renault fully confirmed the results presented by von Gümbel, while more recently new confirmation has come through the investigations by Potonié.

For the most part conclusions reached after microscopic study of coal concern chiefly the question as to the origin of the coal; some of them will find place on a later page. It is well, however, to consider the origin of the mineral charcoal or fusain, as that material has been deemed important in some of the hypotheses which will demand attention. It is present throughout the series of fossil fuels, even in peats, sometimes scattered in fragments, minute or considerable, scattered through the mass, at others forming distinct layers more or less persistent and up to 2 or 3 inches thick. Two partings in the Pittsburgh coal bed, continuous in an area of not less than 2,000 square miles, consist in most of that area of mineral charcoal mingled with impalpable mineral matter. The term mineral charcoal well describes the material; the vegetable structure is distinct, the substance is soft and soils the fingers.

Rogers⁹⁷ thought that leaves and fronds were brought to the marsh by winds or tides and that such parts as were not reduced quickly to condition of pulp, might remain as mineral charcoal, if the volatile constituents were removed rapidly. Three years later, Daubrée⁹⁸ studied fibrous coal from Saarbruck near Altenkirchen. Some specimens are pure black, with the fibers very fine, and resemble charcoal but are more tender; the fragments are irregular, angular and show little rounding of the edges. There is no transition between this and the surrounding coal and, according to Schimper, the fibers suggest those of coniferous wood. At the same locality is a dense type, less black, less brittle but very like charcoal; it contains 48 per cent. of ash. The material bears no resemblance

⁹⁷ H. D. Rogers, "Origin of Appalachian Coal Strata," etc., p. 462.

⁹⁸ A. Daubrée, "Examen de charbons produits par voie ignée à l'époque houillère et à l'époque liasique," *Bull. Soc. Géol. de France*, II., Vol. III., 1846, pp. 153-157.

to coke, to coal changed by dikes of igneous rock. He is certain that this fibrous coal could not have come from spontaneous decomposition of fibrous twigs, for in that case it would be like the enclosing coal. It is remarkably like the ordinary wood charcoal made by fire and it differs from coal as well as from anthracite by the structure and the volatile content. The ash varies from a trace to 70 per cent. He thinks that this fibrous coal is evidence of fires and refers to a great conflagration in 1844 near Saint-Leon in Landes, which was caused by lightning and destroyed 100 hectares of forest. In the discussion, A. Pomel dissented from Daubrée's conclusions because the quantity of this anthracitic fibrous material is too great to be the result of forest fires.

Dawson in 1878 summed up his conclusions which had been published in various forms in the interval from 1846. There is no possibility of accounting for a substance, so intimately mixed with the coal, by the supposition of conflagrations or of subterranean heat. The only satisfactory explanation is that afforded by the chemical changes experienced by woody matter, decaying in the presence of air, as described by Liebig. Mineral charcoal results from subaerial decay, the compact coal from subaqueous putrefaction, more or less modified by heat and exposure to air.

Grand'Eury⁹⁹ found fusain present in great quantity scattered in small patches throughout the coal. Stems of *Medullosa* and *Dadoxylon* are often carbonized and whole trunks of *Calamodendron* have been found converted into fusain enclosed in a crust of coal. Fusain is like charcoal; but some of it was exposed to moisture and dryness alternately. The subdivision of the material suggests the breaking up of wood in dry air; he thinks it indicates an extreme climate, for one does not find fusain in recent lignite or in swamps of today, but he has seen it in the older lignites. In any case it came at first from disintegration in air; other causes cooperated, but maceration does not give fusain.

Von Gümbel's conclusions are similar; the mode of occurrence, its peculiar disintegration and its loose structure show that it was in completely converted condition when taken up by the coal. He is

⁹⁹ C. Grand'Eury, "Memoire sur la formation," etc., pp. 106, 113-115.

inclined to believe that it was formed in free air, exposed to heat and moisture. Fayol¹⁰⁰ found fusain very abundant in the Grand Couche of Commentry. It occurs in isolated or grouped fragments between bright and dull laminæ, sometimes in heaps several meters long and 10 to 20 centimeters thick; he found it in the axes of brilliant laminæ of branches, especially of *Cordaites*, and in very numerous small fragments in the cannel. Fayol presents many facts which lead him to believe that fusain was formed by decomposition of plants in the air.

This material has been regarded by many writers as anthracitic. Perhaps it may have been so before burial, but the supposition that it could not be impregnated with substances coming from decomposition of the surrounding vegetable material seems to be disproved by McCreath's¹⁰¹ analyses. At the same time it contains usually less volatile matter than is found in the enclosing coal, showing apparently that its origin was different. The analyses show a volatile content of from 6.40 to 30.74 per cent. The highest proportion is in specimens from a coal bed underlying the Homewood sandstone, in which the volatile is 48.140; a specimen with 11.36 is from a coal with 26.500; but there is one result, the average of several analyses, which gives 20.98, while the surrounding coal has only 17.070; the lowest, 6.40, is from a coal containing 21.410; while in one anthracite coal, the fusain contained 8.60 while the coal itself had 8.830. It is sufficiently evident that the volatile of the mineral charcoal bears relation in quantity to that of the enclosing coal.

The suggestion that mineral charcoal was derived from forest fires cannot be accepted as a possibility. The quantity produced by a forest fire is comparatively insignificant. The writer is sufficiently familiar with the subject to form a judgment. The Indians were accustomed to set fire to forests in many portions of the Rocky Mountains in order to drive the game to lower levels. The fires destroyed the bark and leaves but left the trunks little more than scarred. These remained upright until, weakened by decay, they were overturned by the wind to form the "laced timber," which was

¹⁰⁰ H. Fayol, "Études," etc., pp. 149, 177.

¹⁰¹ A. S. McCreath, Sec. Geol. Penn., Rep. MM, 1879, pp. 106, 107.

always a terrible obstacle for exploring parties. Equally in the White Mountains of New England and in many portions of the Appalachians, the writer has seen forests of bare stems projecting above the young growth in areas which had been devastated by fires. The coals of Iowa and Missouri, in some beds, contain so much mineral charcoal that one would have to imagine a continuous conflagration for the whole area during accumulation of the coal.

VARIATIONS IN CHEMICAL COMPOSITION.

The independent history of the several benches of a coal bed is shown not only by the physical contrasts but also by the contrasts in chemical composition, which often are very great. Study of these makes evident that the period of time represented in some localities by a half-inch parting of mineral charcoal and impalpable clay may have been so long as to bring about serious changes in the surrounding conditions. Here one is concerned only with contrasts which seem to be original and not with those which may be due to influence of agencies belonging to later times.

The Bernice coal basin in Sullivan county of Pennsylvania is almost 40 miles from the anthracite area and the dips are extremely gentle. The area is insignificant, 600 yards wide and 2,400 yards long; yet it affords illustrations of differing composition which show the influence of very local conditions. The basin was described by Platt and the analyses were made by McCreath.¹⁰² Platt's section shows two coal beds separated by 65 feet. The lower, 2 feet thick, has

Water	4.130
Volatile matter	15.270
Fixed carbon	67.362
Sulphur	0.523
Ash	12.715

with a fuel ratio of 1:4.41. Another analysis from a different part of the mine has very slightly less volatile but 3 per cent. more of

¹⁰²A. S. McCreath, Sec. Geol. Surv. Penn., Rep. *MM*, 1879, pp. 82, 94, 97; F. Platt, *ibid.*, Rep. *GG*, pp. 176, 189-193.

ash. This coal does not coke and the rather voluminous gas burns with a feebly luminous flame. After drying at 225° F., the coal absorbs water rapidly, regaining within 2 hours about 60 per cent. of the quantity originally present.

The higher bed, known locally as Coal *B*, gives as the average of the three benches a fuel ratio of 1:10.289, an anthracite according to the ratio but an ordinary bituminous coal in appearance. The three benches show no notable difference in composition and the gases burn with feebly luminous flame. One mile away, a coal bed was seen, whose relations to the others could not be determined. At one opening it has 14.085 of volatile and 16 per cent. of ash, the fuel ratio being 1:4.57, and the gas burns with a non-luminous flame. At another opening the structure is, coal, 1 foot 3 inches, slate and fireclay, 6 feet, coal, 3 feet 8 inches; McCreath analyses show for the benches

	Water.	Volatile.	Fixed Carbon.	Sulphur.	Ash.
Upper bench.....	7.930	21.410	54.099	0.551	16.010
Lower bench.....	2.910	11.780	81.672	0.598	3.040

Ignoring the water and ash, the results are,

Upper bench	28.354	71.646	1:2.57
Lower bench	12.606	87.394	1:6.93

These Bernice coals, belonging in the lower part of the Pennsylvanian, differ from those in other small areas within Sullivan county, which, with fuel ratio of about 1:6, yield gas burning with brilliant flame. All are approximately at the same horizon. McCreath's reports contain many illustrations of noteworthy variation in composition of the benches.

The Spitzbergen coal¹⁰⁸ of Jurassic age is in appearance a typical coal. The bed mined in 1904 on Advent Bay is double; the upper bench averages about 3 feet and shows the same features throughout; the lower bench is 1 foot thick. The coal from the upper is

¹⁰⁸ J. J. Stevenson, "The Jurassic Coal of Spitzbergen," *Ann. N. Y. Acad. Sci.*, Vol. XVI., 1905, pp. 85-89.

hard, grayish black and with a fracture more or less conchoidal; while that from the lower is black, lustrous and somewhat prismatic, with some mineral charcoal. These coals were analyzed by A. S. McCreath, who obtained as the average of several determinations for each

	Water.	Volatile.	Fixed Carbon.	Sulphur.	Ash.
Top.....	3.310	19.790	62.763	0.467	13.670 gray
Bottom	4.696	28.560	57.171	0.413	9.160 light brown

The fuel ratio for the top is 1:3.17 and that for the bottom is 1:2, there being a difference of somewhat more than 9 per cent. in the volatile matter.

Gruner says that the Grande Masse of the Rive-de-Gier formation is double, the benches being separated by the "nerf blanc," a white sand parting less than one third of an inch thick. The lower bench or "rafford" is hard and dull, suitable for use in grates, but the upper or "marechal" is tender, brilliant, less rich in oxygen and employed in making gas and coke. There is very great variation in the several parts of the Grande Couche at Decazeville but, according to Fayol, the Grande Couche at Commentry seems to approach homogeneity throughout.

Barrois,¹⁰⁴ interested by the work of Muck, Stainier, Strahan and others bearing upon this question, secured analyses of the coal from several beds near Aniche (Nord), the samples being taken for each decimeter from roof to floor. The ash varied in one bed from 2 to 8 per cent.; in another from 2.2 to almost 8; in a third, from 1.6 to 11.6 and in a fourth from 1 to 6.4—the faux-toit and faux-mur being neglected. The beds are thin, from 0.6 to 1 meter, and the samples were taken without reference to the partings. The results show definitively that conditions were not the same throughout the accumulation of even a single bench. The volatile in different parts of a maigre coal varied 6 per cent. and in a demigras coal, 8 per cent.

¹⁰⁴ C. Barrois, "Observations sur les variations de composition du charbon dans certaines mines d'Aniche," *Ann. Soc. Géol. du Nord*, Vol. LX., 1911, pp. 177-186.

Reports on composition of coal show similar variations in all coal fields.

Some coals cake when heated, others do not. The available methods of analysis lend no assistance toward explanation of the difference. Some have supposed it to be physical, that the glance or caking laminæ are separated so completely by the dull laminæ that fusion becomes impossible; but this can hardly be regarded as established, for in some portions of the Connellsville basin, the coal cannot be distinguished in hand specimens from the non-caking coal of Massillon, Ohio, yet it yields the standard coke. Nor does the proportion of mineral charcoal seem to be important, since the caking coal near Uniontown, Pennsylvania, has as much as some non-caking coals of Missouri. It has been suggested that the Cretaceous coals of Colorado and New Mexico are caking in some localities, non-caking in others, because of the nearness or distance of igneous rocks. Unquestionably, there is much to be said in favor of this suggestion, yet there is much room for the other suggestion that possibly coincidence may have been mistaken for cause and effect. It is not certain that the influence of dikes can be exerted very far through coal or the accompanying rocks. Several of the coal beds in southwestern Pennsylvania are of caking coal, while there are others in the immediate vicinity whose coals are non-caking. There is no reason to suppose that eruptive rocks have exerted influence there. Incomplete conversion of the material as shown by the action of caustic potash is supposed by some to account for non-caking property, there are coals of Cretaceous age, which are attacked energetically by caustic potash, yet make a firm coke. The suggestion has been made that possibly the presence or absence of sapropelic material may determine the extent of caking. This is possible.

The analyses by Carnot¹⁰⁵ led him to interesting conclusions. He procured 18 samples of coal from Commentry, representing several genera of plants. Ultimate analysis showed that the elementary composition of these coals is almost accurately the same throughout,

¹⁰⁵ Ad. Carnot, "Sur la composition et les qualités de la houille, en regard à la nature des plantes qui l'ont formée," *C. R.*, Vol. 99, 1884, pp. 253-255.

but proximate analysis showed great differences in volatile constituents, due to difference in combination of the elements. Ignoring the ash, he found the volatile and the coke as follows:

<i>Calamodendron</i>	35.3	Well agglomerated.
<i>Cordaite</i>	42.2	Rather swollen.
<i>Lepidodendron</i>	34.7	Well agglomerated.
<i>Psaronius</i>	39.5	A little swollen.
<i>Ptychopteris</i>	39.4	A little swollen.
<i>Megaphyton</i>	35.5	Well agglomerated.

He found similar contrasts in modern woods, almost identical in composition, and his conclusion is that plants preserved in coal appear to have different properties though having the same elementary composition, and that external influences were not the only ones affecting the composition and character of the coal. A casual examination of the table might lead one to suppose that the proportion of volatile matter had its influence on the tendency to cake, since the well-fused coke was given by coals with about 35 per cent.; but this may be only a coincidence. Washed "slack" from the Pittsburgh coal at Laramie, Pennsylvania, contains, without ignoring the ash, as high volatile as even the *Cordaite* coal of Commentry; it was tested extensively more than a third of a century ago, its coke was strong and with it some extraordinary runs were made in a furnace, 100 feet high. All that one can say is that caking may be due to the presence of special hydrocarbons—a sufficiently safe and at the same time a sufficiently broad suggestion.

THE INORGANIC CONTENT OF COAL.

The ash or incombustible portion of coal varies in quantity and composition not only in different beds but even in the same bed, horizontally as well as vertically. It may be fine, powdery, a constituent of the coal itself, or it may be coarse, cindery, coming in great measure from slates or partings. Glance coal is often almost free from ash but the matt coal always has more while the cannels very often have a high proportion.

In making an effort to compare coals, one is dependent neces-

sarily on such analyses as can be reached; but here, at the very outset of the inquiry, the worth of these analyses is a matter of doubt. Formerly, samples were selected at random, fragments taken from a heap were supposed to represent the average of the bed. For many years, however, sampling in the United States has been on the commercial basis and very frequently the effort has been to ascertain the run of mine composition. Analyses of samples collected according to the different methods are, evidently, not of equal worth for comparison, though it must be conceded that in a very great proportion of cases, results obtained by the old method are remarkably like those obtained by the new.

Allied to this is the other query as to how much of the deposit is to be considered in determining the impurity of the coal. There are those who, in a discussion like this, would throw out of consideration all partings, thick or thin, and would consider only the coal itself, holding that partings, as interruptions in the process of formation, have only indirect bearing on the subject. But others maintain that no part of the bed should be neglected, as the deposit must be considered as a whole. There is some degree of propriety in each contention. Study of the coal itself gives a nearer approach to the nature of the vegetable material forming the coal, it may give approximately a conception of what may be termed the original inorganic material; while study of the whole deposit may give a clue also to foreign matters introduced during formation. Yet one finds himself confronted at once by a question as to the significance of partings; in one locality they may be mere films of fusain and impalpable clay separating benches of the bed, whereas in another, one or more of these partings may have swollen to a mass of shale or sandstone or both, many yards thick. Some coal beds, like the Waynesburg, have clay partings, 6 to 12 inches thick. Occasionally one of these persists after the underlying or overlying bench has disappeared. The question arises Should the sample be taken where the partings are thin or where they are thick? Should the sample be taken where the bed is practically single and another where the bed is divided, the latter to include the intervening sandstone, shale and perhaps limestone?

Comparison of analyses means not much unless one knows the method of choosing the samples; no definite conclusions respecting conditions under which coal was deposited can be based on a mass of analyses gathered indiscriminately from all quarters of the globe. It might be that the ash would tell much, if all portions of a bed were studied, each by itself; but even then the information might be too localized. Another difficulty is that published analyses, with a small proportion of exceptions, are of coal supposed to have commercial value, so that they do not give a proper conception of the character of the greater part of coal beds. Thus, Stainier¹⁰⁸ compared 2,568 analyses, gathered from reports on coal areas in Europe and America. Of these only 15 per cent. showed more than 10 per cent. and less than 2 per cent. had more than 20 per cent. of ash. It is very certain that the 2,250 analyses, giving less than 10 per cent., were not all made of prisms representing the whole bed; and equally that the coal was taken from localities which were promising from the commercial standpoint. This is beyond dispute, since more than one half of the analyses report 5 per cent. or less of ash. It is unsafe to take the average of such analyses as representing a probable average condition. Most of the coal horizons show extreme variations which at times are abrupt, so that, while a sample from one locality may have but 5 per cent., another, only a short distance away, may have 25 per cent. It is quite probable that if analyses were made of all the coal beds in some small areas of southwestern Pennsylvania, where the column is long, the results would show that more than half of the beds have more than 10 per cent. of ash. One must recognize that in many localities the conditions did not favor the accumulation of clean coal; in the higher portions of the Coal Measures, within the bituminous region, the beds are all poor, broken by thin slates, no analysis showing less than 12 per cent. and most of them above 16 up to almost 32.

The difference in ash-content of the benches of a coal bed may be very great. A. S. McCreath's analyses of several beds in Pennsylvania show, for those in the Allegheny, differences between the

¹⁰⁸ X. Stainier, "Notes sur la formation des couches de charbon," *Bull. Soc. Belge de Géol.*, Vol. XXV., 1911, P. V., pp. 73-91.

upper and lower benches of 16, 13, 14, 12, 11, 9, 8, 7, 5, 4, 3, and 2 per cent. Sometimes the upper, at others, the lower is the less clean. Often there is no difference in appearance but usually the cause of greater impurity is distinct, for the filmy partings of black shale are apparent. Local variations are equally well marked in analyses by the same chemist. The ash in the Lower Freeport varies from 1.80 to 10.53 per cent. and in the Middle Kittanning from 3.48 to 12 per cent., the samples in every case being of coal which is mined. It must be evident that a collection of analyses from all regions cannot be utilized for generalization. Conditions varied locally at each horizon, so that while worthless coal was accumulating in some places, good coal was accumulating in others; equally, the conditions varied greatly during the period of formation, so that one bench may be clean and another worthless.

But a promiscuous collection of analyses is not merely worthless as a basis for generalization, it is also very apt to be misleading by diverting one's attention from consideration of the features which are really important. One is not concerned with averages of coals all over the world or in the proportion of analyses showing more or less than 5 per cent. The really important matter is the composition of a particular deposit within a large area. When this has been ascertained, one finds that the difficult problem is not to account for the excess of ash but for the astonishing deficiency in ash, observed in some beds throughout very great areas. Analyses by A. S. McCreath and by Hite and Patton¹⁰⁷ show that the Campbell's Creek coal bed in 4 counties of southern West Virginia gave as the result of 26 commercial samples, 5.943 per cent. of ash and all were of outcrop coal, yet 10 of them had less than 5 per cent. In 4 other counties, the average of 34 commercial samples is 5.52 per cent. and several had less than 3. Commercial samples of the Pocahontas coal from 38 localities in southern West Virginia showed from 2.34 to 9.58 per cent., with an average of 4.63. The Pittsburgh usually has 7 per cent. or less. All of these are in areas of from 2,000 to 6,000 square miles or more. Evidently there are coal beds which in

¹⁰⁷ W. Va. Geol. Surv., Vol. II., 1903, pp. 695, 696; Vol. II. a, 1908, pp. 393, 394.

immense areas have not so much ash as one should expect; they have less than the original plants should have contributed. This is the important matter for consideration; there is no difficulty in accounting for high ash in coal, but there is great difficulty in accounting for coal which, in areas of thousands of square miles, have too little ash.

The ash in different beds as well as in different parts of the same bed may show notable differences in composition. The White Ash coal bed, of Upper Cretaceous age, near Cerillos in New Mexico, is of interest because in the mines one can follow the coal in its passage from high grade bituminous, thoroughly caking, with 39 per cent. of volatile, and 5.24 of ash, to a typical anthracite with 93 per cent. of fixed carbon and 5.78 of ash. This change takes place within little more than 2,000 feet and is due to influence of a sheet of andesitic rock. Church¹⁰⁸ analyzed the ash from both types, the samples being taken from car-load lots and representing the coal as shipped to market. His results are:

Silica	26.93	32.14
Alumina	32.41	36.58
Oxide of iron	3.96	12.86
Lime	24.68	8.19
Magnesia	10.32	5.11
Sulphate of calcium	0.21	0.18
Soda		1.36
Potash	1.49	3.59

McCreath¹⁰⁹ has given the composition of ash from 2 samples of Red Ash and 7 of White Ash anthracite which may be compared with that from the bituminous Upper Freeport at 3 localities in Jefferson and Clinton counties.

The bituminous coals contain 4.150, 3.100 and 9.125 per cent. of ash respectively. A series of 21 analyses given by Muck¹¹⁰ show similar though greater variations. The silica is from 1.700 to 53.600; alumina from 2.210 to 41.110; sesquioxide of iron from

¹⁰⁸ W. D. Church, cited in J. J. Stevenson, "The Cerillos Coal Field," *Trans. N. Y. Acad. Sci.*, Vol. XVI., 1896, pp. 117, 118.

¹⁰⁹ A. S. McCreath, *Rep. M.*, p. 27; *Rep. MM.*, p. 375.

¹¹⁰ F. Muck, "Die Chemie der Steinkohle," pp. 98, 99.

	Red Ash.	White Ash.	Jefferson.		Clinton.
Silica	47.190	48.250	44.82	39.25	47.585
Alumina	35.522	36.177	42.41	39.20	40.117
Oxide of iron.....	4.700	3.290	5.30	13.55	6.143
Lime.....	3.640	1.950	1.44	3.87	0.960
Magnesia.....	0.965	0.921	3.90	2.90	0.731
Sulphuric acid.....	0.712	0.490			0.392
Phosphoric acid.....	1.958	0.923		0.26	0.123
Titanic acid.....	0.990	0.750			1.190
Alkalies, loss.....	7.313	7.249	2.13	0.77	1.486

5.590 to 74.800; lime from 1.080 to 21.540; magnesia from 0 to 9.823; potash and soda from 0 to barely 1 per cent. McCreath reports a small quantity of alkalies in nearly all cases. Where the proportion of iron is large the coal is pyritous. Potash is present in all terrestrial plants, though not always as carbonate. Dieulafait¹¹ examined the ashes of 168 specimens of recent *Equiseta* collected at various localities in Europe and northern Africa. Alkaline carbonates were wanting but calcium sulphate and potassium sulphate are present in large proportion; yet plants of other types, growing in the same localities, gave ash of the ordinary kind, rich in carbonates and poor in sulphates.

The ash analyses to which reference has been made are for the most part from coals without notable commingling with slates. It is altogether probable that ash from commercial samples would show the same materials, though no doubt in slightly different proportions, as it would contain silts brought in and deposited on the forming coal. But in this connection, one must not forget that wind may contribute towards addition of foreign materials. The presence of atmospheric dust is an only too familiar phenomenon on sea as well as on land, but one is in danger of underestimating its importance. James Douglas has informed the writer that coke from Connells-ville, exposed in heaps to the winds of Arizona for a few weeks, showed almost 30 per cent. of ash, though it originally contained not more than 14. This change was in the arid region where dust is abundant, but it suffices to show the possibilities elsewhere.

¹¹ M. Dieulafait, "Composition des cendres des *Equisetacées*," *C. R.*, Vol. 100, 1885, pp. 284-286.

Taylor¹¹² compared the ash of good and bad coal with underclay, bituminous shale and blue shale. The constituents are alike in all though the relative proportions differ. The good coal with 1.36 of ash and the poor coal with 16.9 of ash compared with the underclay show

Silica.....	59.66	64.21	62.44
Alumina.....	12.19	28.78	31.22
Sesquioxide of iron.....	15.96	2.27	2.26
Lime.....	9.99	1.34	0.75
Magnesia.....	1.13	1.12	0.85
Potash.....	1.17	2.28	2.48

Bischof thinks that the analyses show close relationship throughout and that they indicate sedimentary origin for all the materials alike. He says that the variation in composition of the earthy matters in coal is not greater than in shales. McCreath has analyzed many of the Pennsylvania fireclays and the results show great variation, the silica from 47 to 66 and the alumina from 18 to 35 per cent. A similar variation is found in the Pleistocene clays. The resemblance between coal ash and the clays ought to be close in respect of constituents, it matters not whether the coal is allochthonous or autochthonous, but some of the differences offer abundant ground for speculation.

The large proportion of clay in coal ash is, for some, evidence that the material is of extraneous origin, since clay is an extremely unimportant constituent of plants. It is insignificant in the ash from peat. Mills and Rowan¹¹³ give analyses from 27 Irish localities which show in the ash 0.129 to 10.705 of alumina, but 12 of them have less than 1 per cent. and only 3 have more than 3 per cent. It must be remembered, however, that the trees and the peat forming plants of the recent period are not the same with those which gave the coal. The most important plants during Coal Measures time were lycopods and equisetæ. Dana¹¹⁴ cites analyses of some

¹¹² H. Taylor, cited by G. Bischof, "Elements of Chemical and Physical Geology," London, 1854, pp. 268, 269.

¹¹³ E. J. Mills and F. J. Rowan, "Chemical Technology," *Amer. Ed.*, Vol. I, 1889, pp. 16-18.

¹¹⁴ J. D. Dana, "Manual of Geology," 4th ed., 1895, pp. 74, 75, 663.

forms belonging to those types, which show for lycopodium ashes 22 to 57 per cent. of alumina and 10 to 14 per cent. of silica; for *Equisetum*, no alumina but 41 to 70 per cent. of silica. The ash of lycopods is 3.2 to 6 per cent. of the dried plant; of ferns, 2.75 to 7.56; of *equiseta*, 18.71 to 26.75. Stainier cites Wolff, Czapele and Violette; lycopods have 4.70 to 6.10 per cent. of ash; conifers contain very little ash in the wood but their bark and leaves have much more, the former from 1 to 2 and the latter, from 5 to 7 per cent. Coville¹¹⁸ has given a table of analyses, showing the quantity of lime in leaves of trees, the percentage of the dried leaf varying from 1.73 in the red oak to 4.38 in the ginkgo, the modern representative of the *Cordaites*.

Lycopods compose the greater part of most coals, other plants giving the less part—though there are beds consisting very largely of *Cordaites*. Dana has calculated that if the original ash were 1.66 of aluminium silicate and if the plant material lost three-fifths of its mass during transformation into coal, there should remain 4.15 of silica and alumina, the total ash being 4.75 per cent. of the coal; and this without introduction of any inorganic matter from without by either wind or water, the whole being derived from the soil in which the plants grew. Coal is known to consist very largely of flattened stems, the cuticle alone remaining; the other parts of plants have been almost wholly decomposed into a structureless pulp, of which not a little may have been removed by solution. Bark and leaves make up a very great part of the coal. One should expect to find in ordinary coal not much less than 6 per cent. of ash, or even more, in which silica and alumina should predominate greatly.

Yet there is the all-important fact that some coal beds in areas of several thousands of square miles have not merely less but even very much less than the normal quantity of ash. The fact that many coal beds have more is unimportant; no one, be he allochthonist or autochthonist, finds any difficulty in explaining the excess of inorganic matter. But the Pittsburgh, Campbell's Creek, to make no reference to some other beds, have less and the condition in those

¹¹⁸ F. V. Coville, "The Formation of Leafmold," *Journ. Wash. Acad. Sci.*, Vol. III., 1913, p. 80.

beds is not local; they are mined in all parts of their areas and yield scores of millions of tons each year; the analyses are of commercial samples so that they show more ash than the coal itself would show, apart from the thin partings of mud due to overflows. These coals have less inorganic matter than the plant substance should have yielded, which shows that, where accumulation proceeded in a normal way, the product is likely to contain diminished ash. In advancing change by metamorphosis or otherwise the ash is reduced, as appears from analyses of the New Mexico coal and of coals from the anthracite fields of Pennsylvania.

It is wholly probable that not a little of the original inorganic content was removed in solution. Maceration takes much from flax and Fayol ascertained that the same effect is produced on hemp. Wood floated down the Rhine loses much during the journey. Besides this, the organic acids form slightly soluble salts with several bases, which would be removed by leaching. Evidently some areas in southeastern Kentucky, where a coal bed shows less than 1 per cent. ash in commercial samples, must have been in an exceptionally favorable position, where the accumulating coal was protected from flooding by muddy water but exposed to leaching.

THE ROOF.

The normal roof of a coal bed is shale, often resembling that of the mur in composition but differing in structure. Roof shale is more or less laminated but ordinarily there is no trace of lamination in the underclay. In what may be termed normal conditions, the passage from coal to roof is gradual, there being a faux-toit, in which foreign matters increase gradually until at the top all traces of coal have disappeared. This may be a bone or a bony coal, with external appearance of cannel, or it may be a coarse worthless coal, made up of alternating layers of bright coal and black shale loaded with leaves or flattened stems. It may be only a few inches thick or it may continue, as in the Pittsburgh bed, through 3 to 16 feet of measures. Sometimes, the passage is abrupt, as seen at the partings or, so to say, the subordinate roofs of a coal bed, which, as has been

seen, often mark crises in accumulation of the mass. Not infrequently the sand and clay laminæ of the roof disappear and the coal is almost a solid layer, but evidence of unfavorable conditions still remains in the high ash.

At many localities the roof shale, composed of fine materials, contains a profusion of plant remains, stems, fronds, leaves, retaining the most delicate markings. Prostrate tree-trunks have been traced in some cases scores of feet and twigs, with the branchlets and leaves attached, have been found in considerable areas, the fossils often as perfect as though they had been preserved in a herbarium; the fronds of ferns at times show all parts in place and as little disturbed as though they had fallen at the foot of the parent plant. The whole arrangement indicates a gentle deposition of the silts as that during overflow of the bottom swamps by muddy water during rise of a Mississippi flood. But this is not always the condition. Renier¹¹⁶ states that one rarely finds in the Belgian coal fields such remarkable specimens as are described as occurring in other countries. For the most part, the plant remains are fragmentary. So in the Appalachian basin; there are many localities where the remains are beautifully perfect and there are many others in which the remains, though retaining the delicate surface markings, are fragmentary and distinctly not in place. The silts were not deposited as gently in some places as in others. Occasionally vertical stumps are seen, with their roots spread out in normal position over many square yards and still preserving the fragile rootlets, which pass off in all directions as in a living plant. These erect trunks, standing amid prostrate stems and vegetable debris, such as one finds on the surface of forested swamps, rarely pass upward from the coal. It is true that there would be difficulty in tracing the tree downward in case the peat became structureless coal and that the opportunity to make the effort would be a rare one in a mine worked for commercial output, but occasionally the exposure occurs and a

¹¹⁶ A. Renier, "Observations paléontologiques sur le mode de formation du terrains houillers belges," *Ann. Soc. Géol. de Belgique*, Vol. XXXII., 1904, Mem., p. 261 et seq.

geologist happens to be present at the time. Wilkinson¹¹⁷ states that near Newcastle he saw several trunks of trees, up to 1 foot thick and with roots attached, starting from a coal seam and embedded in the strata in the original upright position: More commonly the trees found in the shales with attached roots *in situ*, though of the same general character as those making much of the coal, are not rooted in the coal itself but in the shale. In not a few cases, their relations suggest that they grew on spaces covered with detritus, such as one sees in the large forested swamps, where trees, belonging to species rooting indifferently in peat or in inorganic matter, are growing on sand or clay-covered spaces and with their roots extending beyond to the peat itself. Partings in coal beds unite in themselves the features of roof and floor; at times they contain abundance of plant remains and still serve as soil on which a new vegetation arises. Renier has given an illustration. The roof shale of a coal bed is about 4 feet thick. It contains 12 species of plants but, at a little way above the bottom, there appear in addition *Stigmariæ*, which increase in number toward the top where one reaches another coal bed. In some cases the rootlets of *Stigmaria* have pierced the leaves of other plants, but in most cases they have avoided that exertion and have moved around them. Robb, Williamson and others have described *Stigmaria* rooted in parting clays and Williamson has told of a stem rooted in the parting and passing upward into the coal.

The roof shale varies in color from gray to black, is usually quite fine in grain and argillaceous, though often notably arenaceous. The features are as characteristic in later formations as in the Coal Measures. The dark color is due to organic matter, which is not always derived wholly from land plants, since the deposit at times is not of flood-plain origin. The roof of the Upper Freeport coal bed exhibits the contrast. In extensive areas, it is of the ordinary type, with reasonably well preserved plant remains, but, at some widely separated localities, it contains along with very fragmentary plant remains great abundance of marine fossils, belonging to types

¹¹⁷ C. S. Wilkinson, "Mines and Minerals Statistics of New South Wales," Sydney, 1875, p. 130.

commonly regarded as requiring deep water. The Middle Kittanning in much of Ohio is easily recognized by means of its marine shale roof. Lesquereux has mentioned several instances in Kentucky and the Pennsylvania geologists have added many more. Absence of plant remains is reason for suspecting that the shale is not a terrestrial deposit, even though remains of animals appear to be wanting. Boulay¹¹⁸ was puzzled in several instances by a roof apparently normal but without trace of plants. Very close examination revealed an exceedingly thin layer with *Mytilus* at 4 or 5 inches above the coal. In many cases within American coal areas, the prevailing forms in the roof are *Lingula* and *Orbiculoidea*, which are shallow water forms, but there are roof shales, usually somewhat sandy, containing *Productus*, *Spirifer* and other forms which belong to the so-called deep-water fauna. The condition is quite commonplace in modern times. Instances of peat deposits directly underlying marine clays and sands were given on preceding pages and many additional instances could be cited if necessary.

Limestone is by no means an uncommon roof; it is characteristic of several coal beds within the Beaver formation. I. C. White has recorded many instances in Pennsylvania; Orton, Jr. and A. A. Wright have done the same for Ohio and I. C. White reports the same condition at localities in southern West Virginia. At all of these localities the limestone is marine; but contact with the coal is not found throughout, for very frequently the coal and limestone, in contact at one locality, are separated by several feet of shale or even sandstone at others. The lowest coal bed of the Allegheny in Ohio often is in contact with the overlying marine limestone, and the Harlem coal bed of the Conemaugh is at times directly under the marine Ames limestone, though usually a considerable mass of shale intervenes. So in the Illinois field where Worthen¹¹⁹ found his coals III. and VI. with a marine limestone roof. This is not unusual enough to be surprising; some instances have been reported

¹¹⁸ l'Abbe Boulay, "Recherches de paléontologie végétale dans le terrain houiller du Nord de la France," *Ann. Soc. Scient. de Bruxelles*, 4me année, 1879, sep., pp. 33, 47, 57-59.

¹¹⁹ A. H. Worthen, *Geol. Surv. Illinois*, Vol. III., 1868, pp. 12-13.

from Iowa and Indiana; Tschernychew and Loutougin¹²⁰ state that four coal beds in the Donetz basin of central Russia have marine limestone or calcareous shale as the roof material. Coals of the Monongahela and higher formations frequently have non-marine limestone as the roof material. Lipold has shown that the Triassic coals of his area sometimes have shale but at others limestone roof. Von Gümbel and de Serres have described beds of lignite with limestone roof. Peat deposits have in most cases either clay or sand roofs but calcareous roofs have been recorded on a preceding page.

Occasionally a coal bed is found between marine limestones. Fayol saw at Fontaine near Mariemont in Belgium two beds of anthracite, 3 meters apart, intercalated in marine calcareous shale. He thinks that, according to the *in situ* theory of origin, it would be necessary to suppose that the lower limestone, produced in deep water, was lifted and emerged; then that a submergence of similar amplitude occurred after formation of the first coal bed; that a second emergence succeeded the deposit of 3 meters of limestone and that a second submergence followed formation of the second anthracite bed. Be that conclusion good or not, it is certain that occasionally a coal bed is seen in contact with marine limestone above and below; Illinois Coal VI. not infrequently has this feature, though it must be said that in areas of hundreds of square miles it is separated by several feet of clay below and of shale above. The Tertiary coal at Häring, as well as some south Bavarian coals of the same age, is said by von Gümbel to be between limestones: he thinks that the former was a cedar swamp. Virlet d'Aoust¹²¹ has described the section exposed in a great excavation east from Havre. He saw there 3 characteristic beds of peat, which are merely intercalations in a mass of very calcareous clay, containing abundance of marine shells belonging to *Cardium*, *Mytilus* and other genera.

It is quite possible also for accumulation of coal to be inter-

¹²⁰ Th. Tschernychew and L. Loutougin, "Le bassin du Donetz," Guide des Excur. VII^{me} Cong. Géol., 1897, XVI., pp. 13, 14.

¹²¹ Virlet d'Aoust, "Note sur le terrain d'atterrissements récents de l'embouchure de la Seine," *Bull. Soc. Géol. de France*, II., Vol. VI., 1849, pp. 606-625.

rupted by ingress of marine conditions. The Harlem coal bed at a locality in Ohio and at one in West Virginia has marine forms in the upper part; the condition is common enough in recent times; Belgrand found a peat on the Seine which has many shells and passes upward into a peaty clay and sand, full of shells; Yates described a submerged forest in Cardigan bay where the stems of *Pinus sylvestris* had been bored by *Pholas* and *Teredo*, after which the peat-making was resumed.

Barrois¹²² classified the roofs which occur in a portion of the Nord basin. He found, (1) sandstone, an offshore deposit, with casts of trunks and branches of land plants; (2) shale with plants, carbonaceous, remains abundant and well preserved, by their size and distribution showing short transportation—they fell into the mud from plants or were blown by the wind; (3) carbonaceous shale, thin cannel-like, micaceous and pyritous, with remains of fish—the water was brackish, marine or fresh, little disturbed and deposition was slow; (4) bituminous shale, brown, contains pelecypods and crustaceans—thicker than 2 and accumulated more slowly in fresh or brackish water, is often rich in fragmentary plant remains and in fusain; (5) calcareous shale with marine shells, accumulated in deeper waters open to tides. Numbers 1 and 2, which he terms Group *A*, are to be regarded as deposited by disturbed water on a swampy surface, at times dry and never covered with water more than 5 meters deep. The others, forming Group *B*, were deposited in the deeper water of ponds, lakes, gulfs, as shown by the finer grain and the association of plant remains with those of animals.

Erect trees, parallel among themselves, occur frequently in the area examined. If these had been floated in from the land, they should be found almost exclusively in roofs of Group *B*, deposited in deep water; on the other hand, they should be rare in Group *A*, formed in shallow, muddy water, where they would be buried without being able to retain the erect posture. But the studies show that

¹²² C. Barrois, "La repartition des arbres debout dans le terrain houiller de Lens et de Liévan," *Ann. Soc. Géol. du Nord*, Vol. XL., 1911, pp. 187-196.

there are no erect trees in the deep water roofs of Group *B*, where only broken plant fragments were seen; whereas they are found in the, at most, shallow-water roofs of Group *A*, where leaves occur, *in situ*, spread out flat and intact. In the collieries at Lens, 19 roofs with plant leaves *in situ* have erect stems: 7 of these roofs contain, elsewhere, fragmentary plant remains and lacustrine shells, but not one of these contain such remains in the localities where they have erect trees. All the erect trees were found in roofs of the Group *A* type; not one was found in any roof which is persistently of the *B* type; 28 such roofs exist in the Lens area and all were studied. At Liévan, 7 roofs of the *A* type have yielded erect stems, but none has been discovered in any of the 17 roofs belonging to the *B* type.

These detailed studies, made in small areas where the conditions are apparent, confirm the opinion of Dawson based upon study of the Acadian outcrops and fully justify the conclusion reached by Barrois; erect trees are not found in deposits laid down in water deep enough to permit floatation; they are found only in deposits on which there was never more than a shallow cover of water.

IRREGULARITIES IN THE ROOF.

In all coal beds there are what the miner calls "troubles." Some of these, such as "clay veins" for the most part, are due to disturbance after the column had been deposited, as they pass into overlying rocks; others, irregularities of the bottom, were due, ordinarily, to the uneven surface on which the coal accumulated; but there are many which mark the courses of streams which continued after accumulation of vegetable matter had begun and were obliterated slowly by encroaching plants.

Irregularities in the roof are generally much more perplexing than those in the floor. They are the "washouts," to which reference is made in almost every work on coal fields, and they are closely related to the greater "washouts" or filled valleys. In those to be considered here, only the coal and its roof are concerned. More or less of the coal has disappeared and occasionally the apparent replacement extends even to the underclay. Seen in cross-section,

the foreign material tapers downward as if introduced from above. Often there is no serious distortion, and the coal shows only such irregularity in structure and composition as might be expected if the process of accumulation was more or less interrupted. The variation in the coal is usually such as to indicate that the "trouble" had its origin, at the latest, before the coal was consolidated; but this is not always the case. At the same time, one must not fail to recognize that many times there are disturbances in the immediate proximity, which appear to be directly related to the "washout"; irregular cracks and faultings frequently occur, and the cracks are filled with clay from the partings or even from the "washout" stuff itself. These conditions are due to disturbances of later date; the effect of the force, which caused the gentle folding of the strata, became especially distinct where the mass of resistant rock had been thrust into the brittle coal.

Blandy¹²³ has described the conditions observed in the Red Bank Mining property in Armstrong county of Pennsylvania. The work of removing the coal from these mines had been made unprofitable by "horsebacks," as the miners termed the rolls of indurated clay descending from the roof. These seldom reached the floor but very frequently and for considerable distances, replaced all but 3 or 4 inches of the coal. It was necessary to ascertain the extent of these troubles before reaching a decision respecting farther continuance of operations. Blandy's systematic survey yielded the results presented on the map, which accompanies his paper. These "troubles" mark ancient water-courses. The chief stream was followed for about 1,700 feet and several well-defined branches were mapped. At the southerly end of the workings, another stream was encountered, nearly 100 feet eastward from the former. These stream-courses diverge northwardly, so that at the boundary of the property they are 1,200 feet apart. In another mine, somewhat farther east, the course of a third stream was followed for more than 600 feet, its branches being traced to varying distances. This stream curved

¹²³ J. F. Blandy, "On Evidence of Streams During the Deposition of the Coal," *Trans. Amer. Inst. Mining Engrs.*, Vol. IV., 1875, pp. 113-116.

toward the west in its lower portion, so that if the direction were retained, it would be continuous with a tributary of the main stream within less than 900 feet. Several branches were followed to their heads; in each case the channel became shallower and at length disappeared in the roof. At the sides of all the channels, one finds interlocking coal and clay and the adjacent coal is always tender, finely fractured but pure. The indurated clay, filling the channels, passes upward into shale.

Platt¹²⁴ has described a complicated channel of this type, seen by him in Westmoreland county of Pennsylvania. A "rock fault" in the Millwood Colliery on the Pittsburgh coal bed was traced for more than 1,200 feet. The roof is a grayish clay shale, which, at the edge of the "fault," descends suddenly through the bed and spreads out on the underclay. The sides slope at 20 degrees and upward. The width of the clay deposit averages 100 feet, but in one cross-heading the maximum, 120 feet, was found. Along the median line, wedge-shaped masses of the Pittsburgh sandstone replace part of the clay. Coal is found in the clay at the sides but not elsewhere. Close to the fault, the coal is twisted, hard, lusterless, and has so much slate as to be worthless for fuel. This condition changes gradually away from the clay and at 400 feet the coal equals that from other mines in the region. This description by Platt is that of a filled channel, originally occupied by a stream during the whole period of the Pittsburgh coal, a stream subject to floods and carrying muddy water which left its silt on the vegetation during overflow. The stream became insignificant during deposition of the overlying shale and its narrowed channel was obliterated during the early stages of the Pittsburgh sandstone. Similar "washouts" occur in other mining properties within the district, but their relations have not been worked out.

Descriptions of such channels abound in the reports in several states. Ashley and Udden have recorded instances like those of southwestern Pennsylvania, where the old channel way was filled with a conglomerate mass of pebbles, lumps of clay and coal, with

¹²⁴ W. G. Platt, Sec. Geol. Surv. Penn., Rep. H4, 1878, pp. xxv, xxvi.

stems and branches of trees. The "horse," about which Buddle¹²⁵ wrote many years ago, belongs in this category. This "washout," 170 to 340 yards wide, had been traced for about 2 miles in Colford High Delf seam. The material is sandstone, through which a tunnel had been driven where the width is about 200 yards. Under this "horse," the coal is 4 inches to 7 feet thick and usually it is injured by sand patches from the roof; but it contains no gravel, bowlders or fragments, though the last occur in the sandstone. Some portions of the "horse" consist of sandstone breccia, with pebbles of quartz, like those of the Forest pudding stone—which underlies the Carboniferous limestone—with fragments of coal, ironstone and plant remains. The underclay is wholly regular.

It is unnecessary to cite additional instances. The phenomena are familiar in British, French and German coal fields. They have been observed in the Laramie area of Colorado and New Mexico, and they are characteristic of the vast peat area of the Rhine lowlands, where they have been described by Lorie. All are alike, whatever the age may be; they are the work of sub-aerial streams, some of which existed while accumulation of the vegetable material was in progress, while others began existence at a later date.

FLEXED STRATA.

The presence of flexed shales or coals between beds of undisturbed rocks has been regarded as evidence of slips or slides of soft material on submerged slopes; but they cannot be accepted as evidence of such conditions until, first of all, the existence of the supposed conditions has been proved in other ways: for this structure is so familiar as to be almost normal in all strongly disturbed areas—in the Appalachian basin, in the Nord basin or in the little basin of Commentry. To bring about the condition there must be a soft, yielding material between beds of more resistant rock. Lohest¹²⁶ has shown that movements occur in the coal without disturbance of

¹²⁵ J. Buddle, "On the Great Fault called the "Horse" in the Forest of Dean Coal Field," *Trans. Geol. Soc. Lond.*, II., Vol. VI., 1842, pp. 215, 218.

¹²⁶ M. Lohest, "Sur le mouvement d'une couche de houille entre son toit et son mur," *Ann. Soc. Géol. de Belgique*, Vol. XVII., 1890, Mem., p. 125.

the roof; one notable case being that of the couche Grande Moisa, near Liège, where the coal is so distorted as to be thrown into a succession of hook-like curves. Briart¹²⁷ has given illustrations of similar movements in coal beds of the Nord basin. He had observed the phenomenon also in Italy just beyond the Austrian border. There one finds boghead, with clay beds, between great strata of dolomite, the latter showing throughout the section a remarkably regular dip of 30 to 40 degrees. Aside from this dip, they show no signs of disturbance, but the intervening, yielding rocks have been thrown into complicated folds. Katzer¹²⁸ notes a peculiar case; the upper part of a coal bed has been pushed into complex wrinkles, which occasionally affect the whole bed; but there are no wrinkles in the roof. Strahan,¹²⁹ in referring to a contorted clay parting between undisturbed benches, remarks "obviously the shale acting as a lubricant, has permitted differential movement between the strata above it and those below it." The explanation is manifest everywhere and is not open to dispute.

THE HYPOTHESES.

The reader who has examined Part I. of this work has discovered that, in most cases, an author regards his hypothesis as wholly satisfactory, as explaining all phenomena deserving explanation. The allochthonist greets joyfully each occurrence of pebbles in coal, of land shells in the rocks, of rooted stumps filled with sand, etc., as so much additional evidence in favor of his doctrine; while the autochthonist is equally elated by such occurrences, which are infallible proofs that his doctrine is correct. Observations at given localities are often contradictory, but there is no reason to assume that any observer has asserted, knowingly, an untruth or suppressed, consciously, a truth; yet it is clear that, in some cases, personal equation has played an important part, there being, apparently,

¹²⁷ A. Briart, "Notes sur les mouvements parallèles des roches stratifiées," *ibid.*, pp. 129-135.

¹²⁸ F. Katzer, "Notizen zur Geologie von Böhmen," *Verh. k. k. Reichsanst.*, 1904, pp. 150-159.

¹²⁹ A. Strahan, "Geology of South Wales Coal-Field," Part V., 1904, pp. 65, 66.

strong elective affinity for facts of one type in preference to those of another. At the same time, when one finds that the hypotheses are wholly antagonistic, he is compelled to believe that some must be wrong, and he is led to suspect that the best may be defective.

In considering the several hypotheses, the writer will take for granted that, as the laws of physics are unchangeable, physical agents have always acted in the same way as now, though at times their activity may have been greater and more prolonged than at others; That a hypothesis, to be acceptable, must not be based on assumptions, which are themselves hypothetical or not conceivable in terms of conditions actually known to exist; That inasmuch as knowledge is still imperfect, no hypothesis, satisfactory in all details, can be framed and that there must remain many matters to be studied by investigators in the future. There is no assertion of uniformitarianism beyond that of physical law.

Defenders of the several hypotheses should meet on equal terms in respect to introduction of evidence. Advocates of one group of hypotheses must not arrogate to themselves the right to utilize one type of evidence while denying that right to their opponents. It is hardly legitimate to denounce as tyranny the doctrine of Modern Causes, on one page, while on a later page of the same memoir, a luckless adversary is swept from the arena by the contemptuous assertion, that nothing of the kind is known in recent times. It must be remembered that, in this study, both inductive and deductive reasoning are required. No man ever explored the Carboniferous forests, mapped Carboniferous topography or sailed a Carboniferous sea. Those who defend the doctrine of Ancient Causes, equally with those who defend the doctrine of Modern Causes, reason from the known present to the unknown past. The starting point is absolutely the same for all. Evidence of every kind must be welcomed and an effort made to determine its value. Stratigraphers may not reject the testimony of palæontologists nor may the palæontologists speak slightly of the stratigraphers. For either group to dwell lovingly on errors of the other, committed many years ago, is as absurd as is the effort to discredit the work of modern Egyptologists because their predecessors of half a century ago, in their anxiety to reconcile

Egyptian chronology with that of Ussher, committed themselves in blunders now regarded as ludicrous.

In presuming to discuss conclusions reached by fellow-workers, the writer makes no pretence to superior judicial capacity; during the progress of this work he has discovered only too many proofs that his knowledge is defective, his judgment fallible and his mind on the defensive against novel conceptions. His conclusions are merely opinions based on extended observations in many lands during more than 40 years, and on careful study of literature bearing on all sides of the case. They are offered in the hope that they may prove to be of service to some student in the future.

Hypotheses presented to explain the formation of coal beds fall naturally into two groups; one asserting allochthonous origin of the plant material, the doctrine of transport; the other asserting autochthonous or *in situ* origin of that material. The former conception is the older.

ALLOCHTHONY.

The earliest observers, for the most part, saw in the rocks records of only cataclysmic action; for them, proofs of the Noachic deluge exist everywhere. In cosmogonies from the sixteenth to the nineteenth century, that flood is supposed to have covered the globe as a universal ocean, lashed into fury by winds, so that it tore away forests and bared the mountains; the whole mass of débris was swept into maelstroms, spread over the whole surface and, at length, deposited under selective influence of gravity. The majesty of the catastrophe had grown with the telling, and descriptions had become so vivid that the pictured conditions seemed to be reality. But the ravaging disaster was, in greatest part, imaginary; the Hebrew¹³⁰ chronicle relates nothing to enforce the conception. It describes the deluge as merely a rain flood, which destroyed animals by drowning but did not destroy the trees. There is no assertion of violence, for the clumsy ark drifted at ease throughout, the occupants resting apparently in comfort. The idea, however, was normal; all were familiar with the power of rushing waters, so that there was needed

¹³⁰ Genesis, Chapters VII., VIII.

only a conception of greater torrents in greater areas to give basis for hypotheses respecting the origin of rocks.

The doctrine of flood action was well-outlined at a very early date. Woodward, at the close of the seventeenth century, had announced that materials, swept from the land, sank to the ocean bottom in the order of their specific gravity; this was emphasized by Scheuchzer, Conybeare and several later writers, but it was disputed earnestly by Williams, as not in accord with the actual succession of strata. Applied to coal, modifications were made as acquaintance with the phenomena became more intimate. Some authors, Voigt, Parkinson and, much later, Petzholdt, thought that the vegetable material had been reduced to fluidity on the land before removal by floods; Sternberg and Boue held much the same opinion, for they thought that vegetable materials had been reduced to a pulp before removal and that the change to partial fluidity was produced in the tepid waters of the *primaeval* globe. Conybeare apparently was the first to conceive that a single flood might give materials for a coal bed of any thickness, and Jukes was the first to suggest that coal beds may have accumulated on the slopes of a submerged delta. But in all, one finds the conception of floods, carrying at one time mingled organic and inorganic *débris*, at another, mostly plant materials, but at a third, mostly inorganic substances.

Before undertaking the consideration of *allochthony* as a doctrine, it is well to examine several hypotheses, which have been defended by some eminent *allochthonists* but opposed energetically by others.

Mohr in 1866 revived suggestions by Parrott and Bischof that some coal beds might be accumulations of seaweed, and made them into a generalization respecting all coal beds. His reasoning is without reference to the conditions in which coal occurs; the mass of seaweed is incredibly great; there is enough to account for the coal; what has become of it? it has been converted into coal.

But there are some things needing explanation, with which Mohr does not concern himself. The mass of seaweed on the coast of France, Ireland and the Orkneys is enormous and, in all probability, it has always been so since the present climatic conditions began,

but, neither on those coasts nor on those of the North sea, does one find any considerable accumulations of decayed or decaying seaweed. The search in those areas has been rewarded by the discovery of a few deposits, which suffice to show the possibility of accumulation, while they emphasize the improbability. The ocean bottom has been dredged in all directions by exploring expeditions of many nations, but no trace of a deposit has been found in even the areas where seaweed is most abundant. Mohr thinks that the Spitzbergen coals owe their origin to weed transported by the Gulf Stream. There is sufficient reason for doubting the existence of that stream at the time when those coals were formed; but, in any event, if the stream were existing then and as efficient as now, it could not avail for the work. Robert's¹⁸¹ statements respecting the quantity of weed on the Spitzbergen coast do not bear the interpretation placed on them by Mohr. There may be enough at times, if the wind be right, to make landing on the shelving shore a rather awkward process—it is awkward enough at best—but the quantity is wholly unimportant. Stevenson, in 1904, sailed along the west coast for 150 miles and saw very little seaweed.

In like manner, conditions within the Sargasso sea have been exaggerated. Wierd reports by crews of Columbus's boats, 18 to 40 tons burden, have been repeated with the increment of centuries and have found their way into geological treatises everywhere. Stevenson¹⁸² made two voyages in 1910 across the central part of that sea, where the mass of weed should be densest. The quantity, from the standpoint of Mohr's hypothesis, is utterly insignificant. At times, small patches, perhaps 100 or even 200 feet square, may occur, but they are rare and have brief existence, as they are broken up quickly by the strong trade wind, which keeps the water in constant commotion—the surface being covered almost without cessation by "white caps." The feathery individual bunches of weed, rarely more than 1 foot in diameter, are arranged in lines following

¹⁸¹ E. Robert, "Aperçu des observations géologiques faites dans le nord de l'Europe," *Bull. Soc. Géol. de France*, Vol. XIII., 1842, pp. 24, 25.

¹⁸² J. J. Stevenson, "The Sargasso Sea," *Science*, N. S., Vol. XXXII., 1910, pp. 841-843.

the direction of the wind. Occasionally, several lines are united into a strip, 5 or 6 feet wide, but the bunches are barely in contact, while spaces of 500 to 2,000 feet intervene between the strips. Within the area, where weed is most abundant, the whole mass, in a width of a mile, would form a strip not more than 65 feet wide, if the bunches merely touched; if the material were compressed, so as to bring the parts of each bunch into contact, the strip would be insignificant, not more than 2,500 cubic yards to the square mile. North and south from this small central area, the quantity of weed is unimportant.

Ochsenius¹³⁸ in 1890 made some suggestions, which in later publications he developed into what is known as the "barricade theory." This has been given in detail on earlier pages in Part I. One might hesitate to regard this "theory" as offered seriously; but its author presented it in various forms and discussed it elaborately; some geologists have considered it worthy of refutation, while others appear to have found in it enough of suggestiveness to give it merit. Ochsenius clearly was not familiar with conditions observed in coal deposits and his information respecting river action was imperfect. He cites the statements of writers concerning various localities, but these refer to matters quite irrelevant. The rafts of the Atchafalaya and of the Red river have no bearing upon the question of his dams. The extent and character of those rafts were grossly exaggerated by the early observers, but such as they were, they could not be formed on the rivers imagined by Ochsenius, as they required an enormous drainage area. Of course, barricades could be formed at curves of rivers and they are formed; but they are not such as the "barricade theory" demands. Such a blockade of timber would soon become a dam without lateral spillway, as he suggests; but if it existed long enough, with low water, to permit the fine "Spulgut" passing over to form a bed of carbonaceous shale in the basin, and long enough afterwards, with continuous high water, to permit

¹³⁸ C. Ochsenius, "Ueber das Alter einiger Theile der (süd-amerikanischen) Anden. III.," *Zeitsch. deutsch. geol. Gesell.*, Vol. XLII., 1890, pp. 135, 136; "Die Bildung von Kohlenflötzen," *ibid.*, Vol. XLIV., 1892, pp. 84-86, 98; "Die Bildung der Kohlenflötze," *Verh. des. d. Naturf. u. Aertze*, II., 1896, pp. 224-230.

coarse "Sperrgut" to pass over so as to form a coal bed in the basin, it would be no longer a mere dam: it would be a deposit in the channel-way, miles long, which would be impregnable against any flood: the mighty débâcle, which would sweep out the dam and all accumulated material behind it, the "Rollgut," to make a sandstone and conglomerate deposit in the basin, is beyond the reach of imagination. Being in a lowland, little above sea-level, there could not be any such flood as Ochsenius conceives, since high water would give only a comparatively harmless overflow. But at best, the obstruction would cause the river to seek a new channel-way. That was the effect of the Red river raft; the Sudd of the Nile, overturned trees blocking the channel of the Bermejo in Paraguay, obstructions along the upper Mississippi do the same thing; they are not swept out by the high floods, they merely cause diversion of the stream. The breaking of levees along the Mississippi has no bearing on the matter. Those structures have a moderate base in comparison with their height, whereas the barricade, after centuries of accumulation, would be only a few feet high and miles long.

Jukes saw in the Coal Measures of the South Staffordshire field deposits resembling those on a submerged delta cone; his arguments have been presented on an earlier page. Almost a quarter of a century later, Fayol, after long study of the Commentry coal basin, reached similar conclusions, which, in 1888, he presented in such admirable form, with such skilfull attention to detail and with such apparent grasp of all the features and possibilities, that his conception won instant approval from many eminent geologists in all lands and it was accepted as a final explanation of phenomena in the limnic basins of central France. This "Delta theory" merits careful consideration.

According to Fayol, the basin of Commentry was occupied by a lake, 9 kilometers long and 3 kilometers wide, with greatest depth of 800 meters and with an outlet on the southern border. Rain water ate away the surrounding mountainous region and the transported materials are those composing the beds of conglomerate, sandstone, shale and coal now filling the basin. The distribution of those materials was determined by their specific gravity or their

fineness of grain as well as by the condition of the water—quiet or agitated. The finer, lighter materials were carried much farther than the others before reaching the bottom. The basin was filled eventually by detritus from the Colombier at the northeast, the Bourrus at the north and by several less important streams at the north and west; these giving three “zones” of coarse material without coal. Between those “zones” and separated by the Bourrus deposits, are two areas of less coarse deposits, les Pegauds at the east and les Ferrieres at the west, in which the coal beds are found. Petty streams from the north added their quotas, uniting the deltas along the northern border, but practically no material was brought in from the south. The streams were, all of them, short and torrential. The delta-character of the mass is shown distinctly in the Pegauds area by the steep dip of the beds, which approximates closely that of neptunian or submerged portions of deltas; by the presence of fragments of coal, shale and sandstone in the rocks proving gradual advance of the delta-plain; by slips, of which the proof is seen in folded shales, local faultings, evidence of movements of yielding materials on a steep slope; by local erosions; by the clear evidence of great débâcles; and by the structure of the coal beds, which are not parallel. The absence of horizontal alluvial beds on top is due to gradual deepening of the outlet, which amounted to about 100 meters at the close of deposition. Fayol makes no reference in his work to the Decazeville basin, but, as stated in the report of the Réunion of the Geological Society, his theory was applied to that basin by others, who found the evidence as conclusive as that in Commentry.

In considering this doctrine, one must bear in mind that the matter does not concern the existence of deltas in lakes, for that has never been disputed. Nor does it concern accumulation of vegetable materials in one way or another on the alluvial deposits of deltas, for that too has never been disputed. Fayol's doctrine is that coal beds, like other transported materials, were deposited as part of the neptunian or submerged portions of deltas. Granting, for the present, that vegetable matter to give such coal beds could be brought in by the streams, the only question for consideration here is,

whether or not the phenomena at Commentry and Decazeville justify the conclusions embraced in the Delta theory.

The dips of the strata at Commentry are regarded as all-important evidence, since in much of the area they compare with those observed in some lake deltas. But it must not be overlooked that the steep dips, 20 to almost 50 degrees, are those in the Pegauds area, in the supposed bay between the Bourrus and Colombier deltas. Before formation of the Grande Couche, the Bourrus delta had practically crossed the basin, dividing it into two little ponds, of which the eastern or larger may have had an extent of rather more than 2,000 acres. The coal is on the northern border of this pond or bay, while the outlet was on the south side of the basin. The area of the steep dips is nearly 2 miles from the spot where the Bourrus issued from the mountains and three-fifths of a mile west from the coarse rocks of the Colombier deposits. Its rocks are shales and fine-grained sandstones. It is not on the steep delta slopes, but in the quiet "eddy" between the deltas. The dips in such an area should be gentle, not abrupt. Martins states that, within three-fifths of a mile, the slope of the Aar delta in Lake Brienz decreases from 30 degrees to practical horizontality; De la Beche found the Rhone delta practically horizontal at 2 miles from the shore, while the delta of the torrent of Ripaille, formed in deeper water, showed not more than 10 degrees as the average for half a mile. In every case the decrease is very rapid away from the source of supply and the dip is usually quite gentle within less than a mile, though often very steep at the origin. It would be impossible to explain the steep dips in the Pegauds area, if they be taken as original. But one is not left to surmise in order to explain these dips, for they are not original.

The cause is clear enough; they are due in chief part to disturbance accompanying an outburst of eruptive rock in the northeast corner of Pegauds. This affected not only Pegauds but also the Ferrieres sub-basin, about 3 miles toward the west. This outburst took place when the deposition of Coal Measures rocks had been completed and prior to that of the Permian, which is unconformable. This disturbance crushed sandstones and flexed soft shales between

sandstones; in some places it shattered the coal and rubbed the fragments to polished surfaces, at times reducing the coal and shale to a flaky structure like that of pastry. The conditions are those so familiar in the Logan and Pottsville coal areas of southwest Virginia and southeastern Kentucky, as well as in the Allegheny area of Broad Top in Pennsylvania. They are commonplace in some Cretaceous areas at the west. The extent of disturbance increases toward the place of greatest outburst, where one finds faults and slips in abundance. The remarkable "*Glissement de l'Esperance*" is in no sense due to a slide on the slope of a submerged delta. This *glissement* marks the course of a valley, eroded after the Coal Measures deposition had been completed. It was filled with materials different from those of the adjacent rocks and extended for a considerable distance toward the southeast. Similar material was seen in a fragmentary exposure along the railroad at about 3 miles northwest. When the eruption took place, these new, light-colored rocks of the valley were folded into a close irregular syncline, the finer dark shales of the valley wall were pushed over into recumbent folds and a sharp horizontal fault was made underneath the syncline; other valleys of similar type were observed in the basin. The structure, in its striking features, is in no wise original and has no bearing whatever on the mode of deposition.

Practically no coal in economic quantity was formed in the Comentry basin until after not less than 500 meters of rock had been deposited. Suddenly one comes to the *Grande Couche* in les Pegauds, with maximum thickness of not less than 12 meters, and to a similar bed with greater maximum in les Ferrieres—the other and smaller sub-basin. This abrupt appearance of the great coal deposits is a phenomenon for which the delta theory offers no adequate explanation. The streams had brought down a marvelous quantity of inorganic material, converting much of the lake area into dry land and, of necessity, making much of the still water-covered area very shallow. But during this period, no vegetable materials had been brought down, aside from those composing the insignificant streaks of anthracite along the northern border. The new land on the northern side of les Pegauds, barely half a mile

wide, could not have provided material for the coal, as, only a few years earlier, reckoning time as is done in the *Études*, it had been the scene of a terrific débâcle, which had swept 125,000,000 cubic meters of rock across it and had left the surface strewn with coarse debris. It would seem as though vegetation must have appeared abruptly throughout the drainage area or that the streams must have changed their methods quite as abruptly, so as to devote attention to plants instead of to inorganic materials.

Aside from this, the theory seems to offer no satisfactory explanation of the areal distribution of the coal. Even though the lake had been as deep originally as conceived by Fayol, the pond must have become comparatively shallow prior to formation of the Grande Couche, and the bottom must have fallen off quite gently as it receded from the shore line at the north. One cannot conceive, after reading Fayol's description of the region, that any other condition was possible. The Grande Couche is on this northern border of the Pegauds area, and its present outcrop is less than a mile south from the granite. The outcrop is shaped much like a spreading horse-shoe, with its convexity toward the north. The bed is very thick on the north side of the curve but breaks up into several beds at the west, where it disappears, whereas on the east side it merely thins away. Southwardly, it quickly loses thickness, breaks up and within a short distance it disappears. It is confined to that portion of the area where, of necessity, the water was shallow. There is no evidence of any sort that the water was deep; it will not suffice to assert that the presence of tree-trunks in the coal proves that there was an eddy here and that therefore the water was deep; that is merely an assertion that the fundamental assumptions are true. The presence of those tree-trunks in such wonderful abundance, can be utilized to prove that the doctrine is defective. But that is unimportant; if the conditions were as described in the *Études*, the water was shallow in the area now occupied by the Grande Couche. The middle bench of that coal bed is about 10 feet thick for a considerable distance, very clean, and consists so largely of prostrate tree trunks that it must represent a mass of transported vegetation which could not have been less than 150 feet thick. It is so free

from slaty admixture as to suggest that, during its formation, the streams brought into the area practically no inorganic material. It rests on the Banc des Roseaux, a sandy deposit literally crowded with stems and trunks, and extending apparently no farther than the coal in any direction. The purity of the coal shows that the whole mass was brought down at once, and it is at the head of the recess between the Bourrus and Colombier deltas—where neither it nor the sandy bed below should be.

A flood, so terrific as to sweep such a mass of vegetation from the little drainage area, could not be confined to the head waters of the Bourrus and Colombier; the other short streams between them would also be in flood, pouring their great contribution of water into the pond. There could not be any eddying; the whole surface of the water would be dashing with its load toward the outlet. If that were blocked, much of the deposit would be made along the southern border. But, even conceding that the trees were not deposited there, one must not forget that floods of the supposed violence are of brief duration and that floating wood remains very long time before becoming waterlogged. The surface movement would be steadily toward the outlet; there is no conceivable manner whereby the enormous mass of trees could be pushed against the current so as to be deposited at the head of the pond, where the water was too shallow to float the raft not less than 150 feet thick. But aside from this, the coal is not where it should be. According to the law of deposit on a deeply submerged delta cone, coal should be found crossing the cone in curved lines and it should thicken in the direction of the finer sediments. But there is no coal curving across the Bourrus delta; the coal of the Grande Couche disappears in the direction of finer sediments.

Conditions in the Decazeville basin bear no resemblance to those in the Commentry basin. The relation of the coal beds to old river courses and the variations in thickness are wholly different. The theory that coal beds were deposited on the slopes of submerged delta cones does not account for the conditions observed in those basins; Grand'Eury and Gruner found that theory inapplicable to

the Loire basin. Its author did not assert that it could be utilized to explain conditions in paralic areas, but he evidently expected to find support for it in those also. It is fully evident that it has no application whatever to the Appalachian basin, where the rocks were deposited in horizontal condition. Even now, they are almost horizontal in areas of many thousands of square miles within Ohio, West Virginia and Pennsylvania, where for long distances the dip is from one fourth to one half degree—and this dip is not original, for the region was affected by the Appalachian revolution and the beds were flexed. One nowhere finds any evidence of the submerged, steeply dipping beds of a delta; but the thousands of oil-well records show conformity throughout the Coal Measures column—aside from the variation due to local conditions or to widespread differential subsidence.

The term "Delta theory" is an unfortunate misnomer. "Delta," as ordinarily understood, designates not merely the submerged cone but also and chiefly the horizontal, alluvial deposits, and it at once suggests conditions observed in the lower reaches of great rivers, where the neptunian beds have very gentle slope. But this doctrine concerns only deposits made in small bodies of water by short torrential streams. The formation of a cone, such as the doctrine requires, would be possible only if the water were very deep and the bounding wall precipitous where the streams enter. There is no evidence that the conditions existed. No fault is known on the northerly side, but a limiting fault is indicated on the southerly side of the Commentry basin. There may have been important accumulations of water, at times, due to blocking of the exit or to depression along the fault, but such disturbances could have been of only brief duration. The conditions at Commentry resemble very much those observed along the Upper Rhone, and the writer is inclined to regard the "deltas" of the Bourrus and Colombier as alluvial fans.

Some of the "deltas" in the Decazeville basin have all the characteristics of alluvial fans and the deposits show distinctly the selective action of running water; but there are others which are not due to stream action. The great granite conglomerates, with huge

blocks encased in coarse to fine granitic sand, are merely disintegrated granite, the same as that which one sees at many localities between Montluçon and Decazeville. This is much like the great deposit underlying the Mesozoic coal area in Virginia, described by Shaler and Woodworth.¹⁴⁸ The writer could discover no evidence that a deep body of water occupied the Decazeville basin at any time, but there is abundant evidence that the water area was never extensive, except possibly toward the close of deposition.¹⁴⁹

The doctrine of allochthony is not bound to the hypotheses which have been considered, for some of its defenders have no patience with either the Delta or the Barricade theory. The essential feature of the doctrine is, that vegetable matter growing on the land was removed by running water and deposited in water-basins, there to become coal; but there are individual differences in detail. Woodward, Scheuchzer, Conybeare, Buckland, Murchison, Fayol, de Lapparent, Renault, Ochsénus, Lemiére and Stainier believe that the work was done by energetic floods; Grand'Eury and Sterzel see no proof of devastating floods, but appear to regard great rains and mild floods as sufficient; while de Jussieu, Buffon, Hutton, Faujas-St.-Fond, Naumann and Jukes do not concern themselves with the work of transference, but deal only with distribution after materials have reached the water-area. But for all, the principle of distribution by gravity holds an important place. One author puts the matter compactly. Coal plants grew on continents bordering great depressions, into which the meteoric agencies carried vegetable debris along with materials torn from the land by erosion. As calm was restored, the materials went to the bottom in well-defined order, determined by density; sandstone first, then the mud, then the coal and, finally, impalpable clays reached the bottom to form the roof.

Many authors appear to be convinced that all portions of a

¹⁴⁸ N. S. Shaler and J. B. Woodworth, "Geology of the Richmond Basin, Virginia," 19th Ann. Rep. U. S. Geol. Surv., 1899, Part II., Pl. XXI.

¹⁴⁹ J. J. Stevenson, "The Coal Basin of Commeny in Central France," *Ann. N. Y. Acad. Sci.*, Vol. XIX., 1910, pp. 161-204; "The Coal Basin of Decazeville, France," *ibid.*, Vol. XX., 1910, pp. 243-294.

vertical section must have been formed after the same general fashion. Surprise is expressed because coal beds are believed by any one to have an origin different from that of the sterile beds enclosing them; the presence of marine deposits in a column is evidence that the whole column owes its origin to transported materials. But there seems to be little ground for any generalization of this kind. It can hardly be accepted as accurate for a single bed, though it has been so applied. Perhaps Fayol's statement is the best illustration. He had proved that sandstone and shale are composed of materials transported by running water and that the enclosed fragments of plants had also been transported; shales and sandstones, by increase of plant remains and decrease of inorganic materials, become carbonaceous and, in some cases, pass into coal beds; community of origin throughout is clear. But there is a wide gap here between premises and conclusion. The latter is possible, even probable in some cases, but it cannot be accepted as a generalization, for the contrary is a familiar condition in actual peat deposits, where one often finds all possible transitions from sand or clay, on the border, through sandy or clayey peat to the clean peat accumulating beyond. The general assertion, when applied to a succession of deposits, seems to be equally inexact. Alternations of peat with marine deposits are frequent on the coast of the German ocean and English channel, and some of those peats are continuous with living bogs farther inland. Peat in the Bermudas rests on marine limestone and underlies aeolian limestone. In the same region, one may see a living coral reef, formed on submerged aeolian limestone and now in process of burial under aeolian limestone. A forest in Alaska still remains *in situ*, though a great thickness of transported sands and gravels has accumulated around the dead trunks. On many coasts, forests, submerged for centuries, are still recognizable, though material from the land has almost buried them. Borings in deltas and in river plains show that within a vertical distance of 300 feet one may find land, freshwater and marine deposits.

Distribution of deposits by selective influence of gravity is a very alluring suggestion, especially to those who believe that deposits

can be made only in a considerable body of water—itsself a conception which is in great need of proof. But one must concede that it involves many and serious difficulties in its application to small areas, such as the Commentry and Loire basins, and still greater difficulties when larger areas are considered; the more so when one remembers the proposition presented by some eminent men, that a bed of coal may be the product of a single flood.

Taking the Commentry basin as typical for small areas, one finds that coal accumulation began there only after not less than 500 meters of inorganic deposits had been laid down and a considerable part of the area had been converted into land. The two ponds, Pegauds and Ferrieres, were separated by the barren zone of Montassiégé, débris from the Bourrus torrent. The areas of those ponds were perhaps rather more than 2,000 and 1,000 acres respectively. The floods leading to formation of the great coal beds on the north shore of those ponds were extreme; trees were carried down and deposited with the sands in all directions, erect, inclined, prostrate and, in at least one instance, upside down. The vegetable cover was stripped from the drainage area and the whole mass was swept along narrow gorges through which the torrential streams flowed. This conception of the violence is not excessive; nothing less could do the work; for one must remember that the streams were still young, their gorges had been cut in granite and gneiss; the course must have been tortuous and the beds irregular, with shoals and rapids. When this vast mass of débris reached the water-basins, deep or shallow, they would be churned up by the flood's mad rush for the outlet, through which the water would pour with the force of a lake Bagne débâcle, carrying with it the finer and much of the coarser materials. There could be no selection under the influence of gravity. The Banc des Roseaux, dividing the Grande Couche, contains trees in great abundance, supposed to have been brought down by the streams; no selection was there, for the deposit is not along the main stream line of either Bourrus or Colombier, but in the supposed bay between the deltas. It might be suggested that the flood exercised its selective power before beginning the downward course.

In applying the doctrine to larger areas, defenders of allochthony find many illustrations which they regard as more than important. Much is said of timber rafts on great rivers, the masses of floating vegetation on the Amazon, Congo, Orinoco and other great streams, the rake at the outlet of lake Tanganika, the dredgings by A. Agassiz, the accumulation of drift wood on many coasts and the distributing power of currents. But it is not easy to discover what bearing any or all of these can have upon the formation of a coal bed with its orderly succession of floor coal and roof.

The timber composing the Atchafalaya raft was gathered from caving banks along more than 20,000 miles of river courses; very little of it was contributed by floods. Neither the Atchafalaya nor the Red river raft was a solid mass; each was in patches, separated by considerable spaces of open water. If they had sunk to the bottom, no coal bed would have been formed, there would have been only a mass of sediment enclosing logs. And this was the actual condition discovered, when the floating portion of the Red river raft was removed. But, in any event, the statements respecting the extent and character of those rafts, found in many publications, have been proved to be fabulous. If those statements had been true, if trees 60 feet high had grown on the Atchafalaya raft, those very statements should have restrained allochthonists from utilizing the rafts in their defense, since they go to show the immensely long time required to convert timber to the sinking condition and to show also the great amount of inorganic matter entangled in the rafts. Reference to descriptions¹⁸⁶ by competent observers will be sufficient for the reader. The same remarks apply to all accumulations of driftwood. As has been shown on earlier pages, the observations by uncritical voyagers were inexact; photographs prove that driftwood on coasts occurs in scattered fragments, occasionally collected into loose piles. On the shores of lakes or bays, the wind often drives considerable quantities into masses, upon which waves toss sand or silt. McConnell's detailed examination of driftwood deposits on Lake Athabasca made the conditions clear and showed how erroneous were the conclusions drawn from Richardson's description. Con-

¹⁸⁶ "Formation of Coal Beds," II., these PROCEEDINGS, Vol. L., pp. 548-551.

sidering the extent of area whence driftwood has been drawn, the quantity stranded on coasts is remarkably small. It has been gathered by great rivers of America and Asia to be distributed by currents, which have originated since the Carboniferous.

Conditions on the Amazon, Congo and other tropical rivers lend no countenance to the assertion that great sheets of floating vegetation might have been brought down by rivers into estuaries to aid in formation of coal beds. Those great streams, in time of flood, unquestionably carry matted vegetation in considerable quantity. Earlier pages of this work contain descriptions by travellers, which show little tendency to scientific accuracy, but suffice to prove that the material, thus transported, is far from insignificant. At the same time, granting that strangeness of the phenomenon did not lead the traveller to exaggeration and granting that the statements do not tell even half of the truth, the relevance of the occurrences may well be questioned. No reason has ever been presented to justify a suggestion that streams, such as have been named, could have existed as tributaries to estuaries, in which one now finds the Westphalia-Nord coal basins; nor is there any ground for supposing that if they had existed, they would have carried the imagined sheets of plant materials.

It is difficult to understand why the observations by A. Agassiz have been regarded as supporting allochthony, since they in no wise bear on the questions at issue. There was nothing novel about them except the localities. Every one knew that the muds of ponds and lakes contain twigs, leaves, pollen and spores as well as occasional larger fragments of wood. It was equally well known that the silts on river banks contain transported fragments of plants; that the Mississippi and the Orinoco deliver vast quantities of driftwood into the Gulf of Mexico and the Caribbean sea, and the devastating effects of West Indies hurricanes have been described by many writers. If the trawls had not brought up much plant material with the muds of the Caribbean and those off the California coast, the condition would have been inexplicable. But Agassiz found no evidence of a coal bed in process of formation, he found no evidence of sorting of materials through influence of gravity, he found no proof

of elective affinity inducing plant materials to flock by themselves. He did find mud containing much vegetable and other organic matter. His observations indicate only that much plant material carried into the sea does become waterlogged and does sink to the bottom; but they give no suggestion respecting formation of coal beds, although they certainly explain well some features of carbonaceous shale.

The doctrine of allochthony accounts satisfactorily for many phenomena observed in the coal deposits, such as the fragmentary remains of plants in the roof, the presence of drifted trees in sandstones, the occurrence of marine limestones and many others. But these are explicable quite as easily by autochthony, so that they need no further note at this point. Allochthony, as the writer understands it, offers no adequate explanation of the lamination in coal, which does not resemble that of sedimentation; it fails wholly to account for a structure such as that of the Pittsburgh coal bed, whose thin partings of mineral charcoal and mostly impalpable silt persist in an area of several thousand square miles; its assumption of distribution of sediments under influence of gravity fails when applied to the Appalachian basin, for there the coal, as in Commen-try and in other areas disappears with decreasing coarseness of sediments; it affords no means of explaining the remarkable purity of some beds which yield coal of very high grade throughout continuous areas of 2,000 to 7,000 square miles.

The fundamental assumption of allochthony is that rain and floods can remove the vegetable cover, living or dead, from land areas and can convey it to a water basin, there to be deposited and to become coal. This conception seems to be without foundation in actual conditions and to be based upon study of erosive processes in unprotected or disintegrated rocks. The effects of running water on a cover of vegetation were examined in Part II. of this work. It remains only to present the matter synoptically with reference to statements made in defense of allochthony.

It is well to restate the opinions offered by prominent defenders of allochthony, that there may be no misapprehension. Bischof thought that in the earlier times the land was more densely forested than now and that the streams carried off a much greater quantity

of vegetable matter. Grand'Eury, seeing evidence only of quiet deposition, did not recognize the agency of violent floods; the vegetable debris underwent disintegration and decomposition on the land whence it was removed by rain and ordinary floods. There seems to be no positive assertion in any part of Fayol's work that the floods were of extreme violence, but the torrential character of the streams and their great carrying power are essential features of his explanations. De Lapparent stated the matter with clearness, when he asserted that, in the Central Plateau, vegetable masses descended *en bloc* and were deposited as localized coal beds; so that a single flood might make a coal bed of any dimensions. Renault conceived that as there was no ice cap at the poles, the rainfall was greater, the floods more violent and the quantity of transported vegetable materials much in excess of the present, because the surface was covered with a vegetable growth surpassing that now found in the tropics. Lemièrre thought of deep lakes or lagoons fronted by vast low-lying plains; the contributing area was between the levels of low and high water; it was swept clear of vegetation during floods; a mass of vegetation removed *en bloc* might present the appearance of formation *in situ*; during low water, the streams would bring in little aside from inorganic materials. For Stainier, the plants grew on the continent, whence they were swept into depressions along with inorganic materials, the mass being assorted by specific gravity; the *Stigmaria* being denser, sank into the underclay.

The flooding of vast lowland areas is not hypothetical; the writer, in Part II. of this work, has cited many authors to show that, in the Ganges, Yang-tse-kiang, Amazon, Zambesi, Mississippi and other extensive drainage areas, great floods are only too familiar features; that for long distances, at times hundreds of miles, the lowlands are covered to the depth of many feet in strips 40 to 100 miles wide; the depth in some cases being such that only the tops of the highest trees can be seen. The water for these floods comes at times from highlands far away and is not that from rainfall over the flooded region; at other times, the storms originating in distant highlands pass over the area before the flood reaches the plain; but the characteristics are practically the same in all cases. The flood

is highest in the upper reaches, where the stream is narrower, but decreases in height where the flood-plain becomes wide, unless accessions have been received from tributaries. Floods of this type do not sweep vegetation from the flood-plain. If one accepting the transport doctrine in full should read of conditions in the Mississippi area with its several floods each year, 40 to 60 feet deep in various parts of the lowland region—sometimes converting areas of 10,000 square miles into inland seas—he would expect to learn that that region is in great part a dreary waste, deprived of vegetation and uninhabitable. But not so; it is the home of millions of people; it contains many cities with 50,000 to 500,000 inhabitants; a great part, which has not been cleared for cultivation, is still heavily forested, covered with ancient trees; even the swampy areas, subject to flood from long before settlement by man, abound in the majestic *Taxodium*. These floods lift buildings from their foundations and carry them away; they injure farming land by leaving a deposit of silt or sand; they disturb property relations by undercutting the banks or by digging a new channel across the necks of horseshoe curves; but they usually are of brief duration and normal conditions return.

Transportation of vegetable materials by streams is no matter of hypothesis. Every stream carries on its surface twigs and leaves torn off by the wind; rivers carry great quantities of coarse and fine débris, increased in times of high water by trees and shrubs from caving banks; but the cover of vegetation remains practically uninjured in spite of all attacks. Agassiz, Kuntze, Humboldt, Wallace and other travellers in South America; Merrill, Frankenfield, Humphreys and Abbot as well as other observers in the Mississippi area; Livingstone, Cameron, Baker, Stanley and other travellers in Africa; Medlicott, Blanford and others in India, all tell the same story, as has been shown on earlier pages. The lowland flood rises slowly, it does not scour the surface, it does not destroy the forest growth, large or small, it does not disturb the peat deposits. Even when loaded with cakes of ice, it is powerless against standing trees, as has been observed many times on rivers in the eastern states. The high-level line of floods is ascertained by noting the silt rings on

tree trunks—a method employed in South America, Australia and on the Pacific coast for semi-torrential as well as for lowland floods. The overflow flood, that portion outside of the channel, moves slowly at the bottom and does not scour; instead, it deposits inorganic materials. If forced aside into a narrow space, it may cut a channel; but in that case it has ceased to be a flood and has become a local current. These are characteristics of lowland floods everywhere; the movements of water are governed by the same law throughout the world; there is no reason to suppose that other laws prevailed during earlier periods, to be repealed abruptly at the beginning of the Quaternary.

The floods of torrents can hardly be regarded as supporting the doctrine of allochthony. In some features they resemble those on lowlands, but in many ways the phenomena are different. Ordinarily, torrents flow in narrow valleys, more or less gorge-like with here and there a petty flood-plain, on which trees grow. Some large rivers, such as the Potomac, Monongahela and others rising in the Appalachian chain, are torrential during flood in the greater part of their length, but differ from the ordinary torrent in the width of their valleys and of the wooded flood-plains. In all, the rapidity of flow suffices to carry off the water, with, at most, trifling overflow of the plain, the chief change being in the channel which may be widened or deepened. At ordinary stages, torrents, in areas of consolidated rocks, transport very little mineral matter and the water is the plain, the chief change being in the channel which may be very great. But the coarse material is pushed along the bottom, except in extraordinary instances, and comparatively little is carried over to the flood-plain. The rushing water does insignificant injury to trees or plants on that plain, in spite of great speed, as was shown well during the great flood of the Potomac. One can see this for himself along mountain torrents, where trees grow to within a foot of the ordinary water line. There are many such torrents in the central plateau of France, whose fierce floods have done no more injury to trees on their rocky walls than is done to trees by the lowland floods of the Seine area; only fallen stems and other unattached

débris are gathered up to be mingled with inorganic débris from the channel-way.

But there are floods, caused by cloud-bursts at the heads of streams with rapid fall in narrow gorges, which are destructive throughout. Such floods, loaded with coarse and fine rock material, scour the little flood-plains, removing soil and trees alike, the latter to be deposited with the mass of mineral débris in any or all positions, vertical, prostrate, inclined or reversed; and with them would be rootless stems broken off from the cañon walls. The condition is wholly similar to that caused by the bursting of a dam, as in the Johnstown or the Lake Bagné disaster. A torrent flowing in a gorge of gneiss or granite, especially if it be so juvenile as those imagined by Fayol and de Lapparent, would be a succession of falls and rapids, over which trees could not be carried unless the depth of water was such as comes from a cloudburst. It is deserving of note in this connection that plant remains occur very rarely in the Siwalik conglomerates, which, as described by Medlicott, were brought down by the fierce torrents of the Himalayan slope. The small quantity of vegetable materials in Coal Measures sandstones is a remarkable phenomenon, for sandstones certainly tell of greatly increased activity in the streams.

But it is evident from the statements by Fayol and de Lapparent as well as by several others who have been cited, that the supply of plant material comes not from immediate vicinity of the gorges but from the whole drainage area. The difficulties in the way of this suggestion are very serious. The upland region of Fayol and de Lapparent must have been covered with a forest, denser than any in the temperates and with an undergrowth like that of a tropical jungle. Renault goes farther and thinks the vegetation of those days more exuberant than that of the tropics at this time. This condition makes the asserted results impossible, so that the conception hardly deserves the exultant compliment by de Lapparent, that it is a triumph of common sense.

If the flood gates of heaven were opened and the flow of water concentrated on one spot so as to work underneath the vegetable cover, the whole surface would be stripped of soil and all else; but

there is no other conceivable set of conditions whereby the supposed cover of vegetation could be removed. The mass of more or less disintegrated and decomposed plant materials on the surface was very thick; rain falling on this would be absorbed and the material would be cemented. The roots of plants would resist movement of the water; those roots form a network which, under very unfavorable circumstances, suffices to check that movement; a handful of loose sandy clay on a sloping shelf in a railway cut is hardly diminished by a dashing shower or the accompanying rills, if only a bunch of grass have thrust its roots through it. How much greater would be the resistance of the dense vegetation, one can hardly conceive. It would be impossible for a flood to retain any force after encountering such a wall, even though the slope were somewhat steep and though the water had been ploughing the surface for some distance. The observations recorded by Marsh¹⁸⁷ make this sufficiently clear. Any one who has stood at the edge of a wooded river-bottom during time of high flood, knows that, no matter how the water rages outside, quiet reigns within that area and the overflow moves gently. Where vegetation is dense, no flood does damage. A flood can never gain speed in a rolling country covered with such vegetation as supposed by Renault and others; within the matt of plants it would be as powerless for injury as is a great mass of snow on a densely wooded slope. One cannot repeat too often or emphasize too strongly that running water does not strip off a vegetable cover, that floods do not uproot forests, do not tear away beds of peat. This has been shown in Part II. of this work. Be it understood there is no reference here to digging of a new channel-ways by *débris-laden* streams; or to such local accidents as disturbances of the vegetable cover by eddies around stumps or large bowlders in an open area; or even to bursting bogs. Such accidents affecting a few rods or even acres, are very important to the farmer whose pet meadow has been ruined, but they are without interest to one studying conditions within areas of many square miles or along flood lines, scores to hundreds of miles long.

Allochthony applies one set of phenomena, occurring under defi-

¹⁸⁷ "Formation of Coal Beds," II., these PROCEEDINGS, Vol. L., p. 531.

nite conditions to the explanation of another set of phenomena, which are impossible under those conditions. It is in constant conflict with what seem to be the established laws in nature. The true explanation of the formation of coal beds may be still unknown, and it may be the lot of chemists, geologists and palæontologists to follow many paths of investigation for many years before discovering the truth; but, to the writer, it appears certain that the path marked by allochthony ends in a *cul de sac*, walled with contradictions; and that farther investigation along that path will be fruitless; for allochthony magnifies the exceptional into the normal and endeavors so to explain away the normal that it may appear to be the exceptional.

AUTOCHTHONY.

According to the doctrine of autochthony, the plants, yielding material for the coal, grew where the coal is now found; this is not to deny that some deposits were made of transported materials; that would be to deny the evidence of one's senses; but such deposits are of limited extent and have definite features, which distinguish them sharply from deposits made in the normal way.

CANNEL AND BOGHEAD.

The peculiar structure of cannel compelled geologists to recognize that in origin it differed from the ordinary coals. Newberry in 1857 asserted that it is merely vegetable mud, composed of macerated cells, deposited in ponds within swamps; Dawson in 1866, J. Geikie in 1872, E. B. Andrews in 1873 and Davis in 1880 enforced this explanation by their observations. In 1880, J. P. Lesley,¹³⁸ correcting an erroneous reference to his opinions, enlarged the conception and anticipated much of what has been announced in later years. His words are

¹³⁸ J. P. Lesley, Sec. Geol. Surv. Penn., Preface to Rep. H5, 1880, p. xxii.

"Cannel coal I regard as vegetable matter macerated in water, mixed with gelatinous water-plants and with the fine sedimentary clay which even the purest current-water always holds in suspension; and I ascribe the origin of petroleum in cannel, as I do the origin of the well-oil, to such water plants and to gelatinous water-animals."

Hutton and Fischer and Rust observed that resinous bodies, cell-like in character, are abundant in cannel and similar materials; von Gümbel in 1883 found in cannel a wonderful mass of disks and spores with flocky clay, macerated cells and algæ-like plants. Cannel and boghead are surprisingly like the Lebertorf of Purpesseln in East Prussia, which is a collection of parts of plants in a felt-like mass containing insects, leaves, separated cells and pollen grains, there being 1,000 of the last to each cubic centimeter. He felt compelled to believe that cannel, boghead and the Lebertorfs of Purpesseln and of the kurischen Haffs originated in similar manner; and he regarded them as closely related to the Plattekohle of Bohemia as well as to the Tula gas coal of Russia. He observed the algæ-like bodies in the Tasmanite of Van Diemens land. Fröh's studies on peat appeared in 1883. He described the Lebertorf as a liver-brown gelatinous mass, consisting very largely of algæ, there being more than 60 species at one locality; he discovered that the algæ are of comparatively rare occurrence in true peat. Penhallow in 1892 found great numbers of amber-colored rod-shaped bodies in the felted mass of a Mesozoic cannel.

The results of studies by Bertrand and Renault¹⁸⁹ have been given in considerable detail on earlier pages. They examined the boghead of Autun in France and the Kerosene shale of New South Wales. Both contain the flocculent material observed by von Gümbel and Penhallow, in which are the algæ-like forms with pollen grains and vegetable débris. This, they regard as an ulmic jelly precipitated from the brown waters on which the fleurs d'eau floated. An infiltrated substance was observed at both localities, penetrating thalli of the algæ and, in the Kerosene shale, showing a fluidal structure. Some plants and parts of plants absorb it energetically and it penetrates the brown flocculent material or fundamental jelly. Bertrand's later studies were summed up in 1900, when he stated that these "charbons gelosiques" are accumulations of fresh-water algæ in a humic jelly, their fossilization being in the presence of "bitumen." Spores and pollen became fossilized but did not liquefy.

¹⁸⁹ "Formation of Coal Beds," I., these PROCEEDINGS, Vol. L., 1911, pp. 88-93.

They condensed bitumen energetically as did also the hard tissues of plants, which give glance coal. The fleurs d'eau descended in sheets with other accidental bodies, the speed of descent depending on the stage of water; if the water were low, the fundamental jelly would retard or prevent descent. Absolutely tranquil water was essential and the precipitation of ulmic matters by calcareous waters was constant. The "bitumen," absorbed by the various bodies, is regarded by Bertrand as a substance intervening wholly formed and coming from external sources. He suggests that it may have been in the water, but, in any event, he could find no evidence to show that it came from the decomposing plants.

The resemblance of these bodies to algæ was recognized by von Gümbel who saw more than one type, as did also Fischer and Rust, but they entertained enough doubt to prevent them from giving generic and specific titles to the forms. Some later students have felt compelled to dissent from Bertrand and Renault's conclusions respecting the algæ-like forms. Jeffrey¹⁴⁰ subjected the whole series of cannels and bogheads to microscopic analysis. By special treatment he succeeded in reducing the minerals to such condition that he could cut serial sections with the microtome; and in this way he made a great number of slides, giving opportunity for study not possessed by his predecessors. Jeffrey's results confirmed Renault's conclusion that the cannels are composed in great part of flattened spores from vascular cryptogams, which are shown better in American than in European cannels. According to Jeffrey, the bogheads of Kentucky, of Scotland and of Autun contain readily recognizable spores—the forms termed algæ by Bertrand and Renault being really spores of vascular cryptogams—and a similar conclusion is reached respecting the forms observed in the Kerosene shale. Jeffrey is convinced that the well-preserved individual elements in these minerals are spores and he thinks that cannel and boghead are alike in origin. The plates accompanying his memoir are elaborate.

Thiessen's¹⁴¹ results have not been published and only a brief

¹⁴⁰ E. C. Jeffrey, "On the Nature of Some Supposed Algal Coals," *Proc. Amer. Acad. Sci.*, Vol. XLVI., 1910, pp. 273-290.

¹⁴¹ R. Thiessen, "Plant Remains Composing Coal," *Science*, N. S., Vol. XXXIII., 1911, pp. 551, 552.

abstract of his preliminary announcement has appeared. The cannels studied by him are composed almost wholly of spore-exines with resins and cuticles in limited quantity. The so-called binding material in the intestices is distinctly of two substances, one, more or less homogeneous and colloidal; the other, more or less granular, the fragmentary residue of spore-exines. He rejects the algal theory of Bertrand and Renault as well as the sapropelic theory of Potonié, both being undemonstrable. The so-called algæ are not algæ, all forms but one having been proved to be exines of spores, either of Pteridophytes or Cycadofilicates or of both. A gelosic substance such as is called for by the theory is wholly absent.

The exact nature of these bodies, though of extreme interest from the botanist's standpoint, is of subordinate interest here. The important fact seems to be that while these bodies are comparatively rare in ordinary coals, they are predominating constituents of cannell and boghead, thus indicating a different mode of formation. One must bear in mind also, that animal remains are present abundantly in many cannels.

The brown fundamental matter of the cannels and bogheads is apparently the same as that which forms the basis of ordinary coal, and it is supposed by Bertrand and Renault to be a precipitate from the brown waters of swamp-pools, the precipitant being lime. Such brown waters are widely distributed especially in tropical regions. Samples of such water, obtained by Marcato in South America, were studied by Muntz¹⁴² who discovered only a trace of lime in the dark water, which contains 0.028 gramme of organic matter per liter, yet has an acid reaction. The colorless waters are distinctly hard. The authors conclude that the acids were preserved in spite of aeration, because nitrification and consequent oxidation could not take place. When mingled with hard waters, the acids combine with the lime, nitrification begins and destruction of carbonaceous matter proceeds rapidly under influence of high temperature. The quantity of organic acids is small, even when the color of the water

¹⁴² A. Muntz and V. Marcato, "Sur les eaux noires des régions équatoriales," *C. R.*, Vol. 107, 1888, pp. 908, 909.

is intense. Klement¹⁴³ found so little in the almost ink-black waters of Willebroeck that the material could not be investigated thoroughly. He observes that the brown waters of Gouda become decolorized very quickly in presence of pulverized calcite.

Humic and ulmic acids are certainly precipitated by lime; but one may not be regarded as hypercritical if he suggest that this can have very little to do with the supposed precipitation of ulmic matters in the ponds or stagnant waters of swamps. The deposit was laid down in water with undisturbed surface; that would be a stagnant pool, which could be filled only by rainfall or by seepage through the peat. But the seepage water, however rich it might be in lime at its entrance, would lose all while percolating through the peat, as organic acids would take it up; if, in course of time, an excess should exist and should reach the pool, the lime would find no organic acids there, as the bog itself would contain only the insoluble calcium compounds which could not be leached out in appreciable quantity. The condition would be the same, if the pond were fed by a stream meandering sluggishly through the swamp—no other would be possible under the supposed conditions. If the precipitation were a constant process and due to presence of lime, the precipitate should present abundant evidence, for there is no reason to suppose that the lime would be removed at any later time; the precipitation was not merely constant, but also so rapid that a thick deposit of boghead might accumulate in a single season. Everything, under such conditions, would be sealed up quickly. But analyses give no support to this conception of the origin, for lime is an unimportant constituent of bogheads. Liversidge¹⁴⁴ analyzed Kerosene shale from Greta and from Joadja creek in New South Wales. That from Greta contains about 28 per cent. of fixed carbon and nearly 16 per cent. of ash; but of the latter only 1.438 per cent. is lime. The mineral from Joadja creek has almost 16 per cent. of fixed carbon and 9 per cent. of ash; but of the latter only 0.3 per

¹⁴³ C. Klement, "Les puits artésiens de Willebroeck," *Bull. Soc. Belge de Géol.*, Vol. III., 1889, Mem. pp. 259-262.

¹⁴⁴ A. Liversidge, "Descriptions of the Minerals of New South Wales," Dept. of Mines, Sydney, 1882, pp. 162-164.

cent. is lime: no relation exists between the quantity of lime and that of fixed carbon or volatile. If one take the Joadja shale as containing only 10 per cent. of fundamental brown material, the condition remains, as the lime is but 0.027 per cent. of the whole, clearly insufficient for precipitation of the organic acids.

The supply of organic acids must have been very great in order that constant precipitation might be maintained, especially such abundant precipitation as to give several inches of fundamental jelly in the course of a single season—the water being stagnant. Everywhere, the brown waters, even when almost black, contain very little organic matter in solution, one part in 20,000 sufficing to give marked coloration and an acid reaction. The coffee-brown or greenish black waters of South America, according to Humboldt, are preferred to all others for drinking, being limpid and of agreeable flavor. Coville¹⁴⁵ has stated that water from the "juniper area" of the Dismal Swamp, with the color of tea, was the favorite source of supply for vessels departing on long voyages. This is a typical locality in the heart of the swamp; the water is acid in reaction and the flora is of the acid-resisting type, consisting of *Chamacyparis*, alders and heathers. There seems to be no reason for supposing that, during Carboniferous times, the stagnant waters of swamps approached saturation with organic acids.

The suggestion that the "bitumen" is of extraneous origin, that it intervened fully formed, that it may have been in the water, is sufficiently perplexing. Bertrand finds no evidence that it was derived from the decomposing mass. It fills shrinkage cracks in the fundamental matter and it seems to have penetrated some tissues more readily than others—a condition which, for Bertrand, explains some differences in coals; glance, composed of barks and cuticles, absorbed much, but tissues in matt absorbed little. The algæ-like bodies had notable capacity for absorbing this bitumen. Renault¹⁴⁶ has expressed an objection, which, no doubt, presented itself to

¹⁴⁵ F. V. Coville, "The Recent Excursion into the Dismal Swamp," *Science*, N. S., Vol. XXXVIII, 1911, pp. 871, 872.

¹⁴⁶ B. Renault, "Études sur le terrain houiller de Commentry; Flore fossile," *Livr.* 2, 1890, pp. 687, 688, 701, 702.

many readers of Bertrand's memoirs. The invading bitumen must have possessed extreme fluidity, as it was injected into all parts of the vegetable débris, passing even through the walls of cellules; but that fluidity would have led to complete penetration of the sandstones and shales in which one finds the often widely isolated coaled plants; but no evidence of that penetration is seen. He objects also that if the penetration had been made into tissues, the coal should have the appearance of a compact resinous mass; but the coaled wood is porous and he found no "bitumen" in cells and vessels.

The term "bitumen," as employed by Bertrand, is extremely vague and its actual signification cannot be gathered from any of his writings. A reference to the La Brea (Trinidad) conditions suggests that a petroleum is the supposed source. This area was studied by Cunningham-Craig,¹⁴⁷ who states that the Rio Blanco sandstone has so much petroleum that, though tide-washed, it has 15 to 18 per cent. of sticky oil or soft pitch on the surface, and it constantly exudes similar material into the Pitch Lake. The existence of such asphaltic matter would be recognizable in the rock after any period, no matter how long—one finds asphalts in Carboniferous limestones and sandstones. The glance coal in sandstones is caking, rich in bitumen. The objection, however, is not insuperable. A light-colored oil with paraffin base might leave no notable trace in the sandstone. At the same time, one must bear in mind that paraffins do not change, and that the great supply is from Palæozoic rocks. If they penetrated the rocks and the tissues, it is certainly strange that certain solvents extract so little from coal or cannel or boghead. Destructive distillation, under similar conditions, obtains rather abundantly from coals some substances which are almost absent from petroleums.

But one cannot resist the query, Why go outside of the decomposing mass for the source of "bitumen"? If a source can be found in that mass, there seems to be no good reason for searching after recondite sources. Coals, even those of Carboniferous age,

¹⁴⁷ E. H. Cunningham-Craig, "Preliminary Report on Guapo and La Brea District," Council Paper, No. 30, 1906, pp. 3, 4.

very often contain macroscopical masses of resins, which, in color, are very similar to the material revealed by the microscope. Palæobotanists have discovered in ferns certain organs closely resembling those which, in modern ferns, secrete resins and there appears to be good reason for supposing that Sigillarids yielded much resinous material. The gums, resins and other substances, originally soluble or rendered soluble by microorganisms, would be deposited in tissues and crevices. The feature is familiar in recent bogs and those of the Quaternary, where the fluidal ulmic and other allied substances fill not only cavities in the bogs but also in the underlying bed.

The formation of the cannels and bogheads would seem to be explained sufficiently by the earlier conception, which has the double merit of simplicity and of accordance with conditions known to exist. The minerals consist of vegetable muds with contribution more or less important by plants and water animals. The great abundance of spores and pollen grains is paralleled in modern times by showers of pollen, the "sulphur showers" in wide areas; fresh-water algæ abound in pools of actual swamps—possibly their existence in Coal Measures times is still problematical. Modern sapropelic deposits bear, in many ways, very striking resemblance to cannels and bogheads, though certainly there is no evidence of a "bitumen" infiltration. But the hypothesis of extraneous origin of the "bitumen" seems to be unnecessary, so that, to be accepted, it should be supported by incontestable evidence. Lesquereux¹⁴⁸ cites Ziegmann's analysis of an impure peat, which yielded 6.2 per cent. of wax, 0.4 per cent. of resin, and 9 per cent. of "bitumen." It is sufficiently well known that peat, subjected to destructive distillation, gives ample evidence of containing bituminous matter. Theinius, cited by Davis,¹⁴⁹ has shown that air-dried peat yields 6.39 per cent. of petroleum, lubricating oil and paraffin wax, besides 40 per cent. of tar oil. The dried tar yields 54 per cent. of the same substances and a notable quantity of ammonium sulphate. The

¹⁴⁸ L. Lesquereux, Sec. Geol. Surv. Penn., Rep. for 1885, p. 117.

¹⁴⁹ C. A. Davis, "The Uses of Peat," U. S. Bur. of Mines, Bull. 16, 1911, p. 136.

Ziegler process for securing these substances from peat has been tested on the commercial scale, with results approximating those obtained by Thenius.

Autochthonists claim that their doctrine is in accord with what is known of nature's processes and that its fundamental assumptions can be verified by observation. They recognize that in some respects, modern differ from ancient conditions. The distribution of heat on the earth's surface is clearly unlike that during the Carboniferous; the dominant plants of modern forests did not exist at that time. But the Carboniferous plants have relatives in the modern flora; the chemical laws governing decay of plants have remained the same throughout, as proved by a continuous record; the erosive action of running water has shown no change in method; the laws controlling the deposit of transported materials have remained unaltered from the earliest times. There have been great changes in animal and vegetable life; many forms have become fitted to new habitats; but such modifications are not unknown in modern times and they are not regarded as strange.

The modern peat bog is taken to be the analogue of the ancient coal bed. The vegetation is dissimilar, but that is unimportant. Land-plant material, be it of one sort or another, gives peat under the proper conditions. The final substance is practically the same in the cedar swamps of New Jersey, the cypress swamps of the southern states, the swamps of Scandinavia and in the buried swamps of the southern states, the swamps of Scandinavia and in the buried swamps of the Ganges, western India or the Mississippi; and, in all of those, it is the same as that in the great tropical swamps of Florida, Demarara and Sumatra, where it is derived from wholly different types of plants. Everywhere, the final result of decomposition is the same; the plant material is converted into a mass of organic acids and salts, enclosing large or small woody fragments of resistant composition. The difference in plants does not affect the matter under consideration; Carboniferous plants were converted into peat when exposed to the proper condition, just

as are modern plants, the same organic materials being common to them both.

The vast extent of some coal fields is urged as a vital objection to autochthony, because there are no delta-plains so great as the larger coal fields of America or China. But this is not correct. The Ganges-Indus flood plain area, like that of the Yang-tse-kiang, is as great as the Appalachian basin and each has, in a considerable part of its extent, conditions favoring accumulation of peat. Too many writers commit the error of confounding extent of coal field with extent of coal bed, and they refuse to believe that peat could accumulate synchronously throughout the vast areas. Though in no wise enamoured with modern causes, they appeal to them quickly and cite the limited extent of modern peat bogs, none of which resembles the Appalachian coal basin. But these writers forget or do not know that coal was never accumulating at any one time throughout a great field. Even at the time of the Pittsburgh coal bed, with its probable area of more than 12,000 square miles, there was not synchronous accumulation. During the earlier part of that bed's history, as shown on an earlier page, coal was forming in less than one third of the area; and during the later portion there was no accumulation in perhaps half the area. So with other beds; coal accumulated at separated localities, a few square miles or hundreds of square miles in extent, sometimes near together but at others far apart. During most of the time, conditions were unfavorable to coal accumulation in probably by far the greater part of the more extensive basins. One has to consider not vast sheets of coal, but local deposits. The condition, most probably, was that now seen in Holland, Belgium, northern France and northern Germany, where the peat deposits are in separated areas, large and small; but they are contemporaneous and mark a definite horizon. The important continuous area of Holland, Belgium and northern France, now largely buried, is nearly as large as that on which any bench of the Pittsburgh seems to have accumulated; and the thickness in some places is important. The Everglades of Florida is almost as extensive and is only one of the many swamps in Florida, where the distribution is very like that at some coal horizons in the

Appalachian basin. The thickness of certain coal beds has been regarded as weighing heavily against autochthony. But the modern peat bogs, which have been studied in detail, are youthful, of only post-glacial origin. Possibly in course of time there may be at many places peat deposits of immense thickness like those in some portions of the Alaska tundra; but it is more probable that no deposit will excel the average coal bed; reclamation of marsh land has checked peat accumulation in much of Germany and is likely to do it throughout the civilized world.

The earlier writers studied mostly the treeless moors; but many features of coal beds, wanting in those, are reproduced in the Waldmoors or forested swamps, which are familiar in much of northern Europe and in the United States. In all probability they are of much greater extent on the broad plains of the Amazon and Orinoco, where, however, they have been studied only as forested swamps and not as producers of peat. Kuntze has shown that similar areas of vast extent in the Paraguayan region are genuine Waldmoors. The prevailing flora of such swamps in the temperates consists of conifers, heathers, sedges, with ferns and, usually as late arrivals certain mosses. These plants are in a habitat resembling that in which the Coal Measures plants are supposed to have lived, so that there should be important features in common, if the doctrine of autochthonous origin be true—for that asserts that the older flora grew in areas covered with decomposing vegetable materials.

The swamp flora of modern times consists very largely of plants with marked xerophytic or drought-resisting features; similar characteristics have been recognized in the Coal Measures flora, as well as in those of some later coal-making times. The facts that some plants living in swamps are found elsewhere, flourishing on arid or semi-arid soils, has led to the suggestion that they may be only interlopers. Henslow¹⁵⁰ has conceived that the xerophytic features of *Stigmara* and *Lepidodendron* could have been acquired by living

¹⁵⁰ G. Henslow, "On the Xerophytic Characters of Certain Coal Plants, and a Suggested Origin of Coal Beds," *Quart. Journ. Geol. Soc.*, Vol. LXIII., 1907, p. 283.

long on dry ground, and that they could have been retained even after the forms had migrated to a swamp. Seward and Hill,¹⁵¹ on the other hand, recognized indications in the structure that the conditions of growth required development of characteristics associated with the xerophytic habit.

The readiness with which certain types of plants accommodate themselves to the extreme dampness of swamps or to the aridity of sands has been, long time, subject of investigation. Davis¹⁵² says that swamp plants growing at the water-level are drought-resisting; their leaves are contracted, have dense cuticle and are often coated with waxy or resinous materials. The condition against which they are protected exists in swamps as well as in dry soils. Peat, though holding much water, parts with it reluctantly; even after the centrifugal test, the retained water equals 142 per cent. of the weight of the dried peat, and the material appears to be merely damp. Under similar conditions the retained water in sand is but 2 to 4 per cent. There is physiological dryness in peat; the water is ample but not available.

Coville¹⁵³ has shown that another agency is important. He recognizes fully the fact of physiological dryness, but he regards another agency as of equal or in some cases of much greater importance. The blueberry grows luxuriantly in swamps, but equally well in the sandy soil of pine and oak woods on the Coastal plain and in the spruce woods of the White mountain slopes. The factor determining distribution of this plant is acidity, it cannot thrive if the soil be alkaline or neutral. The surface in the pine and oak woods, as in the spruce forests, is covered with a litter of decomposing twigs and leaves, whence organic acids are carried to supply the plant's needs. The rootlets are without the fibrous appendages, which

¹⁵¹ A. C. Seward and A. W. Hill, "On the Structure and Affinities of a Lepidodendroid Stem," *Trans. Roy. Phys. Soc. Edin.*, Vol. XXXIX., 1900, p. 928.

¹⁵² C. A. Davis, cited in "Formation of Coal Beds," these PROCEEDINGS, Vol. L., 1911, p. 601.

¹⁵³ F. V. Coville, "Experiments in Blueberry Culture," *Bur. Pl. Ind., Bull.* 193, 1900; "The Formation of Leafmold," *Journ. Wash. Acad. Sci.*, Vol. III., 1913, pp. 87-89.

characterize ordinary upland plants, so that the absorbing surface is reduced, while the protected leaves prevent rapid loss by evaporation. The rootlets contain abundantly a mycorrhizal fungus, which fills many cells and forms a network outside on the cell wall. Similar fungi were discovered by Miss Ternetz in rootlets of the cranberry and other swamp plants. Coville finds them in most of the acid-loving plants, such as the laurel, birch, chestnut, conifers, oaks, club mosses, ferns, orchids, and thinks probable that they convert the unavailable nitrogen of acid, peaty soils into available nitrogen, so as to provide proper nutriment to the plants.

Fungi, myriapods and insect larvæ are efficient in hastening decomposition. Coville says that myriapods are almost incredibly abundant in the very acid laurel (*Kalmia*) peat. Renault¹⁵⁴ presented to the geological Congress at Paris a synopsis of his great work on the "Microorganismes des combustibles fossiles," in which he indicated the work performed by lower types of life. Study of the Grand'Croix flints proved that micrococci and bacilli abound in that petrified peat as they do in modern peats; he found them abundant in bogheads, cannels, lignite and coal. Mycelia of minute champignons are present in the macrospores of Kentucky cannels as well as in wood fragments of coal beds. The close resemblance to peat conditions led Renault to the conclusion that the plant materials were infected during sojourn in swamps before being swept away by floods, which he believes were extremely violent during Palæozoic time.

CONDITIONS DURING COAL MEASURES TIME WERE FAVORABLE TO ACCUMULATION OF PEAT.

Assuming that the writer's conclusions¹⁵⁵ presented on an earlier page are approximately correct, one must regard the Appalachian basin, at the close of the Pottsville, as in great part an irregular plain, raised not far above sea-level and liable to flooding by many

¹⁵⁴ B. Renault, "Du rôle de quelques bacteriacées fossiles au point de vue géologique," *C. R. VIIIe Cong. Géol. Int.*, 1901, pp. 646-663.

¹⁵⁵ "Formation of Coal Beds," III., these PROCEEDINGS, Vol. LI., 1912, pp. 552, 553.

rapid streams issuing from the Appalachians at the east and the Canadian highlands at the north. The sluggish drainage was rendered more uncertain by irregular subsidence, by formation of gentle plications as well as by local elevation or subsidence in more or less extensive areas. Almost the whole basin was land at the beginning of the Pennsylvanian, as appears from the unconformity between that and the underlying Mississippian, which is marked by an eroded surface in all parts of the area, and by the absence of the Pocahontas and New River beds from the northern portion, except in part of the anthracite area. The gradual northward advance of the Beaver deposits evidences the slow and frequently halted subsidence. The conditions were wholly similar in Indiana and Illinois, west from Cincinnati, and they are equally distinct in Iowa and Missouri, west from the Mississippi river. In all this vast area of perhaps half a million square miles, one finds the unconformity between Mississippian and Pennsylvanian marked by extended erosion, and the first beds of coal, in any district, are irregular, occupying more or less isolated basins in the eroded surface.

The relations of erect tree stems are important in this connection. Much energy has been expended in the effort to prove that transported trees can be deposited in vertical position; but all that energy has been wasted, for no one, familiar with the matter, ever had any doubts respecting the matter. The possibility could not be disputed; the doctrine of chances converted it into a probability and the existence of snags in the Mississippi river made it a certainty.

All such discussion is foreign to the subject and tends to divert attention from the only point at issue, which is, Are these particular stems *in situ* or not? Each occurrence stands alone and it must be considered apart from all the rest.

Erect stems have been observed in all coal fields and often in such relations that not merely unscientific observers but also trained geologists feel compelled to recognize that they are *in loco natali*; Jukes, when he saw the Parkfield stumps, admitted, though somewhat grudgingly, that the trees certainly looked as though they had grown there and that perhaps they had. The observations by Beckett, Ick, Darwin, Goeppert, Sorby, Barrois and others, recorded in earlier

pages, describe trees as clearly *in situ* as are those of Senftenberg, described by Potonié, or the stumps in cedar swamps of New Jersey or the cypress swamps of Louisiana. One is amazed at the manner in which the evidence is received, for not infrequently there is an implication that all may be mere assumption, that possibly other explanations may be found, since no one saw the trees growing. It is an assumption, as is almost everything in the reasoning of everyday life. The writer has seen many extensive areas of cleared land on which the stumps remained; he had not seen the forest in existence, but the relations of the stumps convinced him that they were *in loco natali*. Buried or submerged forests are commonplace now.

The argument in favor of *in situ* origin is based on clear-cut observation. The branches of *Stigmaria* are interlaced in such complex fashion that the most ingenious efforts have failed to explain away the phenomenon, and allochthonists have found themselves compelled to resort to the remarkable suggestions of débâcles and transport *en bloc*; but those were impossible amid topographical conditions such as, according to both allochthonists and autochthonists, must have existed in the Coal Measures areas. It is absolutely certain that no such disturbances accompanied the deposition of the rocks holding the tree stumps, for every feature indicates gentle action; the rhizomas are spread out in normal condition and retain their slightly attached appendages, while the rock itself is the same in all features as it is elsewhere. In many localities, such as those described by Schmitz, Ick, Lesquereux and others in the Coal Measures, Potonié, Darwin and others in the Tertiary, the spaces between the trees are such as are found in forest growth. In some cases, such as those mentioned by Goeppert, Dawson, Grand'Eury and others, successive growths on the same site are recorded, roots of the newer generation descending amid the stems of their predecessors. Not rarely, the roots pierce impressions of leaves previously buried in the soil. At times, prostrate stems are abundant in the intervals between erect stems and frequently the former outnumber the latter; just as one sees on the surface of forested swamps along the Atlantic coast and in the southern states. In not a few cases, the debris of leaves and twigs accumulated about the bases

of the trees, becoming a thin coal bed overlying the roots and extending to a considerable distance. This too is a familiar condition in modern times. "Upland peat," as Coville has termed it, sometimes accumulates to notable thickness in conifer and oak forests: he reports a thickness of 5 feet in some areas. The writer knows only too well that such peat accumulates to a thickness of more than 3 feet in the forests of gigantic firs within New Mexico; on more than one occasion, his camp narrowly escaped destruction because the peaty material had not been removed to the bottom before a fire was lighted.

Erect stems in many cases are cut off abruptly at top or bottom, as abruptly as though they had been sawed off. For this condition, which occurs so often in the roof of coal mines, there is no explanation aside from growth *in situ*. The absence of roots to sawed off stems in the roof, and of crowns to sawed off stems in the mur can be due only to slipping of the coal, which destroyed the original continuity.

The great number of erect stems discovered in the narrow exposures of mines and on the still more limited space of natural outcrops renders wholly reasonable the suggestion that, if coal were mined by stripping, fossil forests would be found abundantly in all fields, as Binney long ago suggested for the Lancashire region. The stems, which have been found, are associated in many cases with ripple-marked sandstones, the ripples at times resembling the complicated forms characterizing dunes or loose sand. Altogether, the evidence showing that the trees, under consideration, grew where they are found, is in every respect as conclusive as is the evidence that the logs between Cape Malagash and Wallace Harbor, described by Dawson,¹⁵⁶ are a petrified raft of driftwood, or that the irregularly distributed battered timber found in sandstones is not a growth in place. The reasoning is the same in both cases, an application of knowledge gained by actual observation to explain conditions where actual observation of the process is impossible.

While the existence of great numbers of trees *in situ*, so dis-

¹⁵⁶ J. W. Dawson, "Some Fossils found in the Coal Formation of Nova Scotia," *Quart. Journ. Geol. Soc.*, Vol. II., 1846, pp. 132-136.

tributed as to suggest strongly that they belonged to forests, may have no direct bearing on the formation of coal beds, it has an extremely important indirect bearing. It is part of the proof that the region was a land area, covered more or less with vegetation. The other elements of the proof have been set forth with ample detail in Part III. They are, the extraordinary horizontality of the strata in many thousands of square miles, where the disturbing forces have not acted, showing marked resemblance to conditions on the Siberian steppe, described by Belt, or to those on the Gangetic plains, described by Blanford; the absence of plant remains in sandstones and shales in great areas; the presence of coal and shale pebbles in many deposits; the gradation in size of pebbles, indicating rehandling by streams; the extreme freedom from fine material along definite lines of coarse rocks, distinct evidence of river selection; the buried valleys, scores to hundreds of miles long; the gullied coal beds; the widely extended sub-aerial erosions: the vast deposits of fine shales, proof of long sub-aerial exposure of the rocks, whence they were derived; the shallow water character of the localized marine limestones, which occupy definite areas, resembling estuaries extending into valleys; the ripple-marks, sun cracks and footprints, observed at many horizons. Some of these features, if they existed alone, might be explained in other ways; but they do not occur alone. They must be considered as a whole. The conditions were such as to favor the accumulation of peat; the coal beds must have accumulated under practically sub-aerial conditions—unless one accept a flexibility of the earth's crust, many times greater than that which some allochthonists imagine is demanded by autochthonists.

THE PEAT DEPOSITS RESEMBLE COAL BEDS.

Grand'Eury says that in the coal the plants have been broken up and the parts scattered; fruits and leaves are separate from their stems; layers of bark have been displaced; the interior portions of stems have disappeared and only the flattened cortex remains; woody parts have been dispersed as fusain; stems are split and torn; *Cordaites* leaves are imperfect; everything, bark or leaf, is

fragmentary; a great part of the tissues was transformed into a vegetable pulp, which makes up most of certain coal beds. Long ago Lesquereux described mature peat in very similar terms, the fragmentary materials being embedded in an amorphous material, consisting of organic acids and their salts. Von Gümbel's description is much the same; the amorphous material, much of which was originally flocculent, is his Carbonhumin, which binds together the plant fragments and the often abundant mineral charcoal, which he terms, *Torffaserkohle*. The cementing material, soluble in the bog, becomes insoluble on drying. Grand'Eury's description of coal applies equally to matured peat, especially well to that of the American cypress swamps. It is thoroughly applicable to the "coal balls" as well as to the Grand'Croix flints, all of which are regarded by investigators as petrified peat.

In one respect, however, the description does not apply to many peat deposits. Coal often consists largely of flattened stems, the interior having disappeared. On preceding pages, the presence of prostrate stems and erect stumps has been mentioned as characteristic of old or new Waldmoors in all parts of the world. According to Harper, such stems and stumps are so abundant in many Florida swamps as to make the peat commercially worthless; Cook says that in the New Jersey swamps stems of white cedar are so numerous that one has difficulty in thrusting a sounding rod through the mass. Similar crowding of stems appears to be a familiar feature in the deposits of northern Europe, according to all observers from De Luc to the present. In very large part, the wood is fairly well preserved; the Irish bog oak and the New Jersey white cedar are utilized by cabinet-makers. Grand'Eury's description affords the explanation. There was little woody material in most of the Carboniferous trees; there is much in the conifers and oaks of modern swamps. But woods of other types do occur in flattened condition within peat; von Gümbel found them at the depth of only one meter, so that the collapse was not due to pressure. Früh made the same observation in the great Digenmoor of the Bavarian highland; the late-Quaternary *Schieferkohle* contains flattened stems of harder woods—and here too the deformation is not due to pressure, for cones, not de-

formed, lie alongside of the flattened stems. Erect stumps are of comparatively rare occurrence in the coal, but they abound in Tertiary and Quaternary deposits. Evidently, cellulose predominated in the older forms as lignin or woody tissue predominates in the newer. As Andersson¹⁸⁷ says, if the cell walls of all plants had consisted of pure cellulose, we probably should have found scarcely a trace of the plant world which once existed upon the earth.

Peat is laminated but not in all cases like coal, for in the latter, the lamination is due very often to flattened stems. The existence of well-preserved woody stems in many swamps obscures the lamination. But Lesquereux long ago recognized the layer-like structure of new peat, where the thickness of layers is not far from an inch, while in the mature peat it is not more than an eighth. Von Gümbel ascertained that compression makes the lamination of even sphagnum peat distinct.

Peat beds have definite benches like coal beds. Lesquereux says that in some bogs the ash is different in color. Such benches are as well marked in peat deposits of northern Europe as in any coal bed and they are equally well marked in the Schieferkohle of Switzerland, so that the history of each bench is clear. The passage from one to another is abrupt, as appears from sections given in Part II. There are, very often, distinct partings, consisting of a crust formed during periods of dryness, when growth of peat is checked and oxidation succeeds; this crust persists after growth has been resumed. Its character is very similar to that of the thin partings in the Pittsburgh coal bed, which consist of mineral charcoal with mostly impalpable inorganic matter, such as would remain after oxidation of vegetable substance. Explanation of those partings in this way seems to very simple and not far-fetched; lowering of the water-level only a few inches would suffice. The period during which that bed accumulated was one of irregular and more or less differential subsidence.

On a preceding page, it was shown that the ash in coal is from less than 1 per cent. to any per cent., the passage from coal to carbona-

¹⁸⁷ G. Andersson, "Studier öfver Finlands Torfmossar och fossila Kvar-tärflora," *Bull. Com. Géol. de Finlande*, No. 8, 1898, p. 191.

aceous shale being continuous, from the chemist's point of view. So with peat, for one may find clean peat with little ash passing gradually into ordinary mud within a mile or less. Coal at times has very much less ash than was contained in the plants whence it was derived; the same is true of peat, which, as a commercial product, has from 1 to 20 per cent. But sphagnum has from 3 to 4 per cent., yet Vohl analyzed a sphagnum peat which contained only 1.25 per cent. of ash.

Coal beds are buried deeply under detrital deposits; but those deposits were laid down, one at a time. Peat beds are of late-Quaternary or Recent age; opportunity for deep burial has come to few of them. But buried bogs are a familiar phenomenon and in some cases the cover is thick. At one locality in Ohio, a bed, 15 to 20 feet thick, underlies 90 feet of sands and gravels; in Indiana, one bed, 2 to 20 feet thick, has been found underlying a considerable area at a depth of 60 to 120 feet. The buried peats of Scotland, France, Germany, Holland, Switzerland, equally with the buried cypress swamps of the Mississippi region and the great buried swamp of the Ganges area, all afford proof that it is not the necessary fate of peat bogs, *in situ*, to be destroyed by oxidation.

The extent of modern peat deposits compares very favorably with that of coal beds; that, extending across Belgium from Holland into France, equals the extent of the Pittsburgh coal bed as it exists to-day. The upper peat bed of the Gangetic plain seems to have been proved in an area of nearly 2,800 miles, exceeding that of any American coal bed except the Pittsburgh and two in the Middle Pottsville. The Alaskan tundra has much greater continuous areas and at some localities the thickness is very great.

Coal beds frequently divide and in some cases the divisions reunite. Peat deposits do the same, as Lorie's records show. True, the divergence of peat benches is not so remarkable as that observed in some coal beds but otherwise the condition is the same; at times, the origin of other features is suggested. The irregular subsidence of the New Madrid region on the Mississippi affected an area of rather more than 2,000 square miles; when that depressed region has been filled up by silts and overspread by a new swamp, division and re-union will be as distinct as it is in the Mammoth coal bed.

Peat deposits rest as do coal beds on sandstone, shale, clay or limestone and the limestone may be either fresh water or marine. Like coal beds they underlie a roof of any sort and at times they are intercalations in marine calcareous shales. The association with marine beds is clearly no evidence of deep water or of flexibility in the earth's crust.

IN CONCLUSION.

The coal beds and the associated rocks are of land origin; the detrital deposits are those made by flooding waters on wide-spreading plains; the coal beds, in all essential features, bear remarkable resemblance to peat deposits, sometimes to the treeless moor, more frequently to the Waldmoor.

But many matters still await explanation, among them some which the writer hoped to explain as result of this study. And they are likely to wait long. No extensive coal field has been studied closely; in spite of the imposing array of skeleton sections, there is an astounding lack of detail respecting many matters which appear to have no important bearing on commerce. Until the topography and geography of the Coal Measures land have been worked out, geologists must be content merely with probabilities concerning the remarkable bifurcation of some coal beds, the variations in subordinate intervals between two approximately parallel coal beds, the presence of huge blocks of transported rock in coal and the associated rocks, the immensely long periods of stable conditions indicated by the thickness of some coals, and some others which will suggest themselves to the reader. It is true that these are all purely local in character, but they occur at many though somewhat widely separated localities. The explanation for some of them must await the solution of certain problems in physical and chemical geology, lying wholly outside of the questions considered in this memoir.

These matters, however, do not concern the general problem with which this study has been concerned. In the present state of knowledge, as revealed in the literature, that finds its solution in autochthony alone.

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ERRATA ET CORRIGENDA.

The frequent omission of the accent in French words was not thought to be important enough to require cutting of the slugs, as it leads to no misunderstanding. There are, however, some errors which need correction.

- Page 2, line 21, for "and" read "amid."
line 23, for "students" read "student."
- Page 19, line 3 from bottom for "observes" read "gives."
- Page 38, line 6, for "Cordiates" read "Cordaïtes."
- Page 67, line 1, for "as" read "at."
- Page 85, line 2, for "Gyranthus" read "Gyracanthus."
- Page 90, line 4, for "port" read "part."
footnote, for "131" read "121."
- Page 97, line 21, for "Coal beds are" read "Coal beds rare."
- Page 111, line 8 from bottom, for "characteristic" read "characteristics."
- Page 219, line 2 from bottom, for "branch" read "bench."
- Page 309, line 16, for "Pennsylvania" read "Pennsylvanian."
- Page 359, line 9 from bottom, for "have" read "has."
- Page 386, the quotation at bottom of page should follow the first paragraph.
- Page 486, the quotation should precede the footnote.
- Page 309. The statement is made here that it is wholly preferable to regard the Pennsylvanian reds as derived from re-working of deposits already red. The writer overlooked the fact that I. C. White had expressed the same opinion after discovering the great extent of red beds in West Virginia. See W. Va. Geol. Survey, Vol. II., 1903, pp. 228, 229; Vol. II. (A), 1908, p. 622.

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